WRDC-TR-89-7006
Volume I

ASSESSMENT OF CREW WORKLOAD MEASUREMENT METHODS, TECHNIQUES AND PROCEDURES

Volume I - Process, Methods and Results

William H. Corwin, Diane L. Sandry-Garza
Michael H. Biferno, George P. Boucek, Jr.
Aileen L. Logan, Jon E. Jonsson
Sam A. Metalis

DOUGLAS AIRCRAFT COMPANY
3855 LAKEWOOD BLVD
LONG BEACH, CALIFORNIA 90846-0001

BOEING COMMERCIAL AIRPLANES
P. O. BOX 3707
SEATTLE, WASHINGTON 98124-2207

September 1989

Final Report for Period July 1986 - February 1989

COCKPIT INTEGRATION DIRECTORATE
WRIGHT RESEARCH AND DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6553

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Michael H. Pharaoh
Wing Commander, Royal Air Force

PAUL E. BLATT
Technical Director

FOR THE COMMANDER

EUGENE A. SMITH, Col, USAF
Director
Cockpit Integration Directorate

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify WRDC/FIGX *, W-PAFB, OH 45433 to help us maintain a current mailing list.*

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS NONE
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE DISTRIBUTION UNLIMITED
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) WRDC-TR-89-7006 VOLUME I
6a. NAME OF PERFORMING ORGANIZATION DOUGLAS AIRCRAFT COMPANY 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION WRIGHT RESEARCH AND DEVELOPMENT CENTER COCKPIT INTEGRATION DIRECTORATE (WRDC/KT)
6c. ADDRESS (City, State, and ZIP Code) LONG BEACH CA 90846	7b. ADDRESS (City, State, and ZIP Code) WRIGHT-PATTERSON AFB OH 45433-6553
8a. NAME OF FUNDING/SPONSORING ORGANIZATION FEDERAL AVIATION ADMINISTRATION 8b. OFFICE SYMBOL (If applicable) APM 430	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-86-C-3600
8c. ADDRESS (City, State, and ZIP Code) 800 Independence Avenue Washington DC 20591	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62201F PROJECT NO. 2403 TASK NO 04 WORK UNIT ACCESSION NO. 50

11. TITLE (Include Security Classification)
Assessment of Crew Workload Measurement Methods, Techniques and Procedures
Volume I - Process, Methods, and Results

12. PERSONAL AUTHOR(S)
William H. Corwin, Diane L. Sandry-Garza inter alia

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM Jul 86 TO Feb 89	89, Sep 12	237

16. SUPPLEMENTARY NOTATION
Supported in part by the FAA

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
			Subjective Measures
05	09		Performance Measures Physiological Measures

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
This report summarizes the work conducted as part of an FAA/U.S. Air Force sponsored contract (F33615-C-86-3600) "The Assessment of Crew Workload Measurement Methods, Techniques, and Procedures". The primary goal of the contract was to identify assessment techniques which demonstrate evidence of validity and reliability and are suitable as measures of flightcrew workload for aircraft certification.

To use a workload assessment technique with confidence for the certification of an aircraft flightdeck, the validity and reliability of the technique must be well established. Validity is the capability of the assessment technique to measure the abstract construct it is proposed to measure. Reliability is the capability of the measure to produce the same results with repeated testing.

A comprehensive literature review was conducted to identify workload measures which have an empirical record of validity and reliability. All candidate workload assessment techniques (over)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL Michael Pharaoh	22b. TELEPHONE (Include Area Code) (513) 255-8279	22c OFFICE SYMBOL WRDC/KT

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE had to be applicable for evaluating workload in an aircraft environment. Two workshops were conducted to bring together experts in the workload assessment field to determine candidate measures for simulation testing (aided by the literature search), and make recommendations for testing in a high fidelity simulation. Two separate simulation tests were conducted at the Man Vehicle System REsearch FAcility at NASA-Ames Research Center using a Phase II B-727 motion-base simulator.

The process by which this contract was conducted allows us to make factual statements regarding the validity and reliability of workload measures. The findings of validity and reliability for the workload measures tested are repeatable as demonstrated by the replication of results in the second simulation study. The method employed in this contract allows for an audit trail of the process by which an assessment technique is determined to be valid and reliable. A summary of the steps compled for this contract includes:

a. Literature review and Fact Matrices
b. Workshop to gather expert agreement
c. Simulation testing.

Workload measures which demonstrated evidence of validity and reliability in simulation testing includes:

a. In-flight and Post-flight subjective ratings (SWAT, NASAOTLX, and Bedford rating scales)
b. Heart rate, as measured by R-to-R wave Interbeat Interval
c. Control Input Activity for the wheel (aileron) and column (elevator) during manual flight path control.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF TABLES
(Continued)

GLOSSARY

ANOVA	Analysis of Variance
ATC	Air Traffic Control
ATIS	Automated Terminal Information System
ATP	Airline Transport Pilot
BCA	Boeing Commercial Airplanes
DAC	Douglas Aircraft Company
EB	Eyeblink Rate
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FM	Frequency Modulation
HR	Heart Rate
HRV	Heart Rate Variability
HSD	Tukey's Honestly Significant Difference
Hz	Hertz
ILS	Instrument Landing System
IBI	Interbeat Interval
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LED	Light Emitting Diode
MEL	Minimum Equipment List
MSe	Mean Square Error
MVSRF	Man-Vehicle System Research Facility
NASA	National Aeronautics and Space Administration
NOTAMS	Notice to Airmen
OAK	Oakland International Airport
OWS	Overall Workload Score

GLOSSARY
(Continued)

PCA	Principal Component Analysis
PF	Pilot Flying
PNF	Pilot Not Flying
PSE	Pilot Subjective Evaluation
PTT	Push to Talk
SBP	Power Spectral Analysis (Blood Pressure Component)
SCK	Stockton Municipal Airport
SD	Standard Deviation
SELCAL	Selective Calling
SFO	San Francisco International Airport
SID	Standard Instrument Departure
SIGMET	Significant Meteorological Conditions
SMF	Sacramento Municipal Airport
SRS	Power Spectral Analysis (Respiration Component)
STAR	Standard Terminal Arrival
STPA	Secondary Task Probe Accuracy
STRT	Secondary Task Reaction Time
SWAT	Subjective Workload Assessment Technique
TLA	Timeline Analysis
TLX	NASA-Time Load Index
TOC	Top of Climb
TOD	Top of Descent
USAF	United States Air Force
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

PREFACE

This report is the result of 2 years of research sponsored by the USAF and the FAA directed toward the evaluation of crew workload assessment techniques for aircraft certification. This study was conducted as a joint effort by the two major U.S. manufacturers of commercial transport airplanes: Douglas Aircraft Company and Boeing Commercial Airplanes. The primary purpose of this volume is to report the results of the contract effort. The objective of this contract was to provide assessment criteria to enable the FAA to evaluate workload measurement plans for crew size substantiation and workload acceptability during aircraft certification efforts, not to define a single measure or battery of measures that each manufacturer must use.

The authors wish to express appreciation to the many pilots from American, Delta, Eastern, TWA, and United Airlines who participated in this project. Extreme gratitude is also expressed to Preston Sult (Boeing Commercial Airplanes) for his participation as First Officer and differences trainer for all testing conducted. Thanks go out to Pat Kullenberg (Douglas Aircraft Company) for his help in creating and debugging the flight scenarios.

The participation of flight engineers, Mike Bortolussi, Hugh Campion, and Doranne VonEnde is also appreciated. The efforts of the Manned Vehicle Simulation Research Facility (MVSRF) of NASA-Ames Research Center, and their simulation sub-contractors Singer-Link and Northrup in the preparation of the simulator and their help in conducting the tests are also appreciated. Thanks to Todd Williams (DAC) for his development of the Fortran programs used to reduce the simulator data. Gratitude is expressed to Vern Battiste and Sandra Hart of NASA-Ames Research Center for their participation in the part-task simulation. The efforts of Janet Camarata (BCA) in the preparation of the final manuscripts is greatly appreciated. Thanks also go to our contract monitors Harry Britten-Austin and Mike Pharaoh (RAF/USAF), and Peter Hwoschinsky (FAA) for their help and guidance throughout this program.

Thanks go to the personnel at the Man-Vehicle Systems Research Facility at NASA-Ames including: Elliott Smith, Rod Ketchum, David Gates, Barry Sullivan, Bob Shipley, Bob Shiner, and the cast and crew who feed the VAX all the 1's and 0's that make the simulation work.

Finally, the authors wish to thank the following student interns from California State University of Long Beach for their help in the data reduction and analyses: David Nixon, Mariel Sipman, Diana Kargoo, Toni LaFranchi, Terry Knight, Judy Wong, and Peggy Dolan.

1.0 INTRODUCTION

In 1981 the President's task force on crew complement reported on workload assessment techniques employed in aircraft certification programs. In general, the workload measures and test domain employed in recent certification programs were judged to be "state of the art"; however, a number of improvements have been recommended for future efforts (McLucas, Drinkwater, and Leaf, 1981). The recommendations include:

(a) Improving subjective measurement methods,
(b) Studying crew performance under a variety of conditions; line operations (full-mission) simulation using selected line pilots used in conducting these studies,
(c) Consulting with qualified line pilots in the area of workload evaluation,
(d) Evaluating the impact on crew workload of selected minimum equipment list (MEL) items.

The "state-of-the-art" technique referred to by President's task force is Timeline Analysis. Timeline analysis, based on micro-motion techniques and borrowed from Industrial Engineering, computes workload as a ratio of time required to complete necessary tasks as a fraction of time available. Timeline analysis is an analytic technique which does not require "pilot in the loop" measurement. Workload measurement techniques can be classified into the following categories:

(a) Subjective ratings,
(b) Physiological recordings,
(c) Performance in the piloting task.

More recently subjective judgements have been used for evaluating the acceptability of flight deck workload during certification. Recent improvements in workload measurement science, however, have led to the perception that other methods for evaluating workload exist, and perhaps they are ready to be employed in aircraft certification applications. The purpose of this contract is to identify valid and reliable workload measures, and provide a methodology for the correct application of those measures in a high fidelity aircraft flightdeck environment.

A list of acceptable workload assessment techniques and scenarios for aircraft certification can be derived upon application of a selection criteria and a set of boundary conditions for the criteria. The minimum criteria for acceptability of a workload measure is that the measure is valid, reliable, and applicable to aircraft certification. The boundary condition should consist of a set of statements which identify the proper domain in which the measure is valid (measures what it is believed to measure) and reliable (stable or consistent in what it measures). Applicable assessment techniques are those which are safe, cost-effective, can be applied in a timely fashion, and can be implemented in the flight deck of a commercial aircraft. The guidelines which are presented in Volume Two are an attempt to specify the important boundary conditions for workload assessment in an aircraft certification program.

1.1 OBJECTIVES

The primary purpose of these guidelines is to enable the FAA and USAF to evaluate workload assessment plans. This is to be accomplished by providing a recommended:

(a) Process for evaluating candidate workload measurement techniques and task scenarios,
(b) Usage of the workload measurement concepts,
(c) List of measures which have exhibited evidence of validity and reliability in the assessment of civil transport workload.

Several specific objectives are identified to facilitate the evaluation of a workload certification plan and are as follows:

(a) Provide guidelines for evaluating a proposed aircraft workload certification plan that will enable the FAA to insure that the workload criteria specified in FAR 15.2523, Appendix D are adequately considered,
(b) Provide guidelines on how to apply workload assessment techniques in aircraft certification,
(c) Provide guidelines for evaluating the adequacy of the proposed workload measures and scenarios included in a workload certification plan,
(d) Provide examples of evaluation criteria for the determination of acceptable workload measures and scenarios,
(e) Provide a data base to aid the FAA and USAF in location of factual information about workload measures suitable for aircraft certification.

1.2 BACKGROUND

Requirements to assess transport aircraft crew workload have developed as a means of assuring that the task demands imposed on the aircrew will not exceed the crew's ability to respond to them in a safe and timely fashion. The requirements for assessment of crew workload are specified in FAR 25.1523 Appendix D and in FAR 25.771 (see Table 1.2-1).

A distinction should be made between the workload experienced by the crew and the task demands imposed on the crew. This distinction is often characterized as a separation between the demands placed on the crew member by the machine and the crew member's response to those demands. The demands of the task are dependent on the requirements of the system, the effort (workload) put forth by the crew member is dependent on his perception of the task demands, and the results of that combined man/machine effort determines the system performance.

The distinction between perceived mental workload and the perceived workload in general, has not always been easy to make. Although early investigators such as Cooper and Harper (1969) have distinguished between physical and mental effort, completely satisfying methods for separating them have not been developed. Physical workload is computed in terms of the actual movements (i.e., eye and hand movements) needed to execute a procedure. Mental workload is assumed to occur when a human operator performs higher order functions such as perception, information processing, or decision-making. Excessive mental workload will manifest itself in the system by longer operator processing time, shedding of tasks, increased errors, performance decrements, and motivational lapses.

TABLE 1.2-1. FEDERAL AVIATION REGULATION REQUIREMENTS

REQUIREMENT

FAR 25.771 PILOT COMPARTMENT

(a) Each pilot compartment and its equipment must allow the minimum flight crew (established under 25.1523) to perform their duties without unreasonable concentration or fatigue.

FAR 25.1523 MINIMUM FLIGHTCREW

The minimum flight crew must be established so that it is sufficient for safe operation, considering - -

(a) The workload on individual crew members;

(b) The accessibility and ease of operation of necessary controls by the appropriate crewmember; and

(c) The kind of operation authorized under 25.1525.

The criteria used in making the determinations required by this section are set forth in Appendix D.

FAR 25 APPENDIX D

Criteria for determining minimum flight crew. The following are considered by the Agency in determining the minimum flight crew under 25.1523:

a. Basic workload function. The following basic workload functions are considered:

(1) Flight path control
(2) Collision avoidance
(3) Navigation
(4) Communications
(5) Operation and monitoring of aircraft engines and systems
(6) Command decisions

b. Workload factors. The following workload factors are considered significant when analyzing and demonstrating workload for minimum flight crew determination:

TABLE 1.2-1. FEDERAL AVIATION REGULATION REQUIREMENTS (Continued)

(1) The accessibility, ease, and simplicity of operation of all necessary flight, power and equipment controls, including emergency fuel shutoff valves, electrical controls, electronic controls, pressurization system controls, and engine controls.

(2) The accessibility and conspicuity of all necessary instruments and failure warning devices such as fire warning, electrical system malfunction, and other failure or caution indicators. The extent to which such instruments or devices direct the proper corrective action is also considered.

(3) The number, urgency, and complexity of operating procedures with particular consideration given to the specific fuel management schedule imposed by center of gravity, structural and other considerations of an airworthiness nature, and to the ability of each engine to operate at all time from single tank or source which is automatically replenished if fuel is also stored in other tanks.

(4) The degree and duration of concentrated mental and physical effort involved in normal operation and in diagnosing and coping with malfunctions and emergencies.

(5) The extent of required monitoring of the fuel, hydraulic, pressurization, electrical, electronic, deicing, and other systems while enroute.

(6) The actions requiring a crewmember to be unavailable at his assigned duty station, including: observation of systems, emergency operation of any control, and emergencies in any compartment.

(7) The degree of automation provided in the aircraft systems to afford (after failure or malfunctions) automatic crossover or isolation of difficulties to minimize the need for flight crew action to guard against loss of hydraulic or electric power to flight controls or to other essential systems.

(8) The communications and navigation workload.

(9) The possibility of increased workload associated with any emergency that may lead to other emergencies.

(10) Incapacitation of a flight crewmember whenever the applicable operating rule requires a minimum flight crew of at least two pilots.

c. Kind of operation authorized. The determination of the kind of operation authorized requires consideration of the operating rules under which the airplane will be operated. Unless an applicant desires approval for a more limited kind of operation, it is assumed that each airplane certificated under this Part will operate under IFR conditions.

1.3 SCOPE

Valid, reliable, and applicable techniques for workload assessment are addressed in the following contract. Issues of overload and underload are addressed only to the degree that those states can be inferred using valid and reliable workload measurement techniques, but no attempt is made to create those situations during simulation so that the candidate measures can be evaluated for their ability to identify those states. Fatigue is another issue related to workload that is not specifically addressed in the simulation studies conducted to evaluate the candidate workload measures.

1.3.1 PROGRAM CONSTRAINTS

Owing to the large number of possible workload measures which could be reviewed and evaluated, certain self-imposed limitations were outlined to insure adequate resources would be available for a reasonable quality evaluation of the candidate measures. The following limitations were outlined:

(a) Workload measures were selected from those which already existed. A candidate measure had to have published evidence of validity and reliability.
(b) The "best" measures were evaluated from each of three categories: Subjective, Physiological, and Performance workload assessment techniques. "Best" was defined as the most valid, reliable, and applicable to aircraft certification. The number of measures to be evaluated was limited by the available resources.
(c) Only measures which were suitable for high fidelity simulation or flight test were evaluated.
(d) Measures were evaluated in a civil transport environment (as opposed to military environments). The types of task demands addressed in scenario selection were identified by, but not limited to, the functions and factors in FAR 25.1523 Appendix D. (The results obtained from scenarios which are common with military task demands will be valid for military applications).
(e) The issues of underload and fatigue were not examined.
(f) A list of "acceptable" workload measures was developed, where "acceptable" was defined as a measure which had evidence of both validity and reliability with representative civil transport workload. An acceptable measure was presumed to be valid and reliable for only specific types of workload. The designation of acceptable did not imply it could be employed in every condition.

Owing to limitations of funding, only the pilot was used as a subject in the current investigations. Even though the simulation test bed was a three crew aircraft (Captain, First Officer, and Flight Engineer) the workload assessment techniques are being considered for use in certification of newer, two-person, aircraft. Newer generations of aircraft utilizing two crew members usually divide flightdeck responsibilities into pilot flying (PF) and pilot not flying (PNF). PF responsibilities are primarily aircraft control and navigation. The PNF is responsible for communication, system monitoring, and any tasks delegated by the PF. The current investigation manipulated workload so that both PF and PNF task demands were represented by the pilot.

1.3.2 DESIGN VERSUS CERTIFICATION

Workload measurement is most effective when the new aircraft design is complete, a high fidelity simulation is available, airplane development testing is completed, and the crew is fully trained. A high fidelity simulator or flight test aircraft can present representative task demands to a crew, thereby maximizing the probability that actual workload levels experienced during line service. Besides its role as a check on the final design to assure that workload is acceptable, workload assessment can also be employed in the design of an aircraft or of one of its subsystems. Caution should be exercised when applying workload assessment techniques during design due to the lack of system integration in the to-be-evaluated flight deck. The combination of systems can produce increases or decreases in workload that were absent during individual system evaluation. Analytic techniques do enable the designer to make relatively conservative estimates of what the crew's task-demands will be so that it will be virtually certain that the actual workload experienced by the crew will be acceptable.

There are workload assessment techniques that might be appropriate for use in the design phase that were not considered in this effort because they are not yet applicable in the certification flight environment. It is the manufacturers' responsibility to select and propose appropriate workload assessment techniques for certification.

The nature of the equipment change should determine the workload assessment method selected for certification. Each specific type design may generate different types of workload, and therefore, different workload assessment techniques may be required. Not all measures are equally sensitive to the different types of workload (e.g., physical vs. mental).

1.3.3 CERTIFICATION APPLICATIONS

The most relevant consideration when evaluating a workload assessment plan is that the proposed workload techniques are adequate for evaluating the anticipated workload for the new flight deck.

In the early days of commercial jet aircraft (i.e., B-707 and DC-8), workload was primarily of a physical nature. When the commercial flight deck of smaller aircraft (less than 200,000 lbs.) was reduced to two crew members (i.e., DC-9 and B-737), the systems contained a higher degree of integration. The evaluation was centered on the physical nature of workload. The workload evaluation focused on the question of the two crew members (one crew member during the case of incapacitation) accomplishing all the needed tasks for flying the aircraft. Next generations of aircraft (the glass cockpits of the B-757/767 and MD-88) retained the two crew member flightdeck, but the move to sophisticated Flight Management Systems introduced new levels of mental workload for evaluation during the workload certification effort. Finally, the latest certification efforts involve traditionally three crew aircraft (MD-11 and B-747/400) being stretched for increased passenger and range capacity, while increasing automation levels and eliminating the flight engineer.

In the past, commercial aircraft manufacturers have used analytic techniques and non-structured pilot opinion for workload assessment. Analytic techniques are of particular value to the aircraft manufacturer since they offer both the potential for identifying and correcting workload problems early in the design phase when the cost of change is relatively low, and a tool which can provide data for certification. One disadvantage to the available analytic techniques is their lack of fidelity in assessing mental effort. With the current shift of flight deck design placing more mental demands on the flight crew, workload assessment has taken on a new challenge. The addition of structured subjective measures to traditional objective analyses can provide information which validates the analytic and simulation based estimates of physical workload and enhances estimates of mental workload.

In addition to the consideration that appropriate assessment techniques be applied, consideration must also be given to valid test methods. A partial listing of common methodological errors is given below:

In addition to the consideration that appropriate assessment techniques be applied, consideration must also be given to valid test methods. A partial listing of common methodological errors is given below:

(a) Demand characteristics are not controlled (e.g., hints are inadvertently given to the subject on how to rate the workload as high or low),
(b) No differences should exist in the test scenario between the baseline and to-be-certificated aircraft, otherwise observed workload differences could be attributed to changes in the test scenario instead of the aircraft,
(c) Order effects of testing (e.g., learning or fatigue effects) are not controlled.

1.3.4 CONSIDERATION OF MILITARY STANDARDS

A review was made of the military standard entitled: Human Engineering Requirements for Military Systems, Equipment, and Facilities (MIL-H-46855A) and the draft military standard entitled: Human Engineering Requirements for Measurement of Operator Workload. The approach taken in this contract of a literature search, workshops, and simulation testing provides a methodology appropriate to addressing the issues raised in the Military Standards documents.

1.3.5 RELATIVE VERSUS ABSOLUTE MEASUREMENT

Workload assessment for certification relies on a relative comparison of workload levels. Typically workload is compared between the to-be-certificated aircraft and a baseline aircraft, which has an established record of safe performance and acceptable workload. It is assumed that the two aircraft are being compared under conditions which are as similar as possible to insure that any workload differences which occur are due to differences in the aircraft design and not to other factors. If the new model aircraft has the same, or lower workload, then it is concluded that the workload is acceptable in the new model. When performing a relative comparison with a new aircraft design, however, there may be instances when workload levels exceed the old design. In cases such as this the increased workload is not necessarily unacceptable, but it may become the subject of a more in-depth workload analysis. These cases need to be considered on a case-by-case basis with all of the operational factors taken into consideration when evaluating the impact of workload increases.

When measuring pilot workload, or any other behavioral measure, it is essential to consider the variable nature of the data. Behavioral data is best described in terms of distributions, since individuals bring different skills to the task of flying it is possible to get a distribution of workload scores from a group of pilots. The "state of the art" of workload science does not allow for determination of a single score for the purpose of workload assessment. Pilot to pilot variability in assessing workload is a consideration which must be kept in mind throughout an aircraft certification effort. No absolute measure of workload ("Redline" associated with an overload condition) is currently available for aircraft certification. Considering the scope and magnitude of individual differences it would be extremely risky to use a single workload measurement technique to determine if flight crew workload is acceptable.

A number of factors influence the ability to generalize or draw conclusions about workload levels made in a comparative evaluation. It would not be appropriate to include a detailed discussion of these factors here, but a partial listing of relevant factors includes:

(a) Representativeness of subject selection,
(b) Number of subjects tested,
(c) Fidelity of task demands or scenarios,

1.4 CURRENTLY USED TECHNIQUES

Today's list of acceptable workload measures is likely to be out of date 10-15 years from today. Any list which is fixed and cannot be modified to accommodate the improvements developed within the workload measurement science could become more of an obstacle than an aid in certifying the design of a new aircraft. For this reason, emphasis should be placed on whether the most useful measure was selected for a particular application, rather than selection of a measure merely because it was familiar or associated with a prior list.

1.5 OVERVIEW VOLUME ONE

The remainder of this report describes the process undertaken in the course of the contract.

To identify candidate workload measures for evaluation, a literature search was conducted. Selection criteria were established and a Fact Matrix developed to facilitate the comparison of various measures with an empirical record of validity and reliability.

Two workshops were conducted to gather expert opinion regarding the workload measures used for simulation and the approach to simulation testing.

Finally, the methods and results of two simulation tests conducted at the NASA-Ames Research Center are presented.

2.0 SELECTION CRITERIA FOR WORKLOAD ASSESSMENT TECHNIQUES

In order to evaluate the utility of a workload measure specific criteria regarding the validity, reliability, and applicability need to be established. The following sections identify specific issues that should be addressed regarding validity, reliability, and applicability.

2.1 VALIDITY CRITERIA

Validity is defined as the capacity of an assessment technique to quantitatively evaluate levels of workload. There are many types of validity, each affecting the ultimate usefulness and acceptability of a workload measure. Not to consider validity when selecting a workload measure is to employ a measure that carries greater risk of giving spurious results, and it may be better to design an aircraft with less information than with incorrect information. At a minimum it is proposed that the following types of validity be addressed during measure selection, testing, and evaluation (Anastasi, 1968):

(a) CONTENT VALIDITY - It is important to determine that the operationally relevant types of workload are being considered. By focusing on the important types of workload found in cockpit operations, more confidence can be obtained that the correct workload assessment techniques will be selected and employed.

(b) PREDICTIVE VALIDITY - (Also known as Criterion Related Validity) Can the measure be used in a predictive fashion to determine levels of workload? This is the most important type of validity for the manufacturer because it provides a basis for making cost/benefit decisions regarding system design.

(c) CONSTRUCT VALIDITY - The construct validity of a workload assessment technique is the extent to which the technique may be said to measure the theoretical construct of workload. Since workload cannot be directly observed, it exists only as an theoretical construct, it must be demonstrated that the measure reflects changes in what would be predicted for the construct of workload. To have confidence in a workload measure, this connection must be demonstrated whether workload is defined in terms of task demands or operator variables. Construct validity is not accomplished in a single experiment or settled "once and for all," it required the gradual accumulation of information from a variety of sources.

(d) FACE VALIDITY - Face validity refers to what the assessment technique appears superficiality to measure and not necessarily what it actually measures. Face validity can become important in how well people use an assessment technique. If pilots or engineers are asked to use or administer a workload measurement system that makes little sense to them, their motivation to follow all the rules is likely to suffer.

2.2 RELIABILITY CRITERIA

Reliability is defined as the capacity of a workload measure to yield similar results with repeated usage. How consistently does the measure yield the same answer given the same measurement conditions? The following types of reliability should be addressed when considering a workload for test and evaluation (Anastasi, 1968):

(a) TEST-RETEST RELIABILITY - The most obvious method for determining the reliability of an assessment method is to repeat the test conditions on a second occasion, and evaluate discrepancies in the two samples. The reliability can be quantified by computing the correlation between the two sets of scores obtained by the same persons on the two administrations of the workload measure. The resulting reliability coefficient can then be compared to established standards for any test and thereby be viewed with some objectivity.

(b) SPLIT-HALF RELIABILITY - A method employed to determine the consistency of an assessment technique, with regard to content sampling, is to divide the assessment into comparable halves and compute the correlation between the two sets of scores.

(c) INTER-RATER RELIABILITY - A method employed to determine the consistency of an assessment technique across different people, is to compute the similarity of each pilot's workload score with every other pilot (or some representative pilot score) in the same test.

For the aircraft manufacturer these types of reliability definitions are appropriate for workload measurement when each is discussed in terms of discrimination. For instance, if an assessment technique is being used to discriminate between high and low "levels" of workload, it should discriminate between high and low "levels" the same way on a second occasion.

2.3 APPLICABILITY CRITERIA

Applicability of workload measures refers to the extent that the measure in question impacts the performance of the transport aircraft mission and is practical. For a workload measure to be applicable in a flight operational environment, it should satisfy a number of requirements. The following requirements may not always be achievable in an absolute sense, but they can be viewed as guidelines:

(a) The assessment method should be as unobtrusive as possible. It should not impose an additional workload on the crew and thereby disturb the very process that it is trying to measure.

(b) The assessment method should be as noninterfering as possible. It should not endanger the crew's safety nor interfere with their normal duties.

(c) The assessment method should be non-career threatening to the crew members it evaluates (e.g., data collected using physiological measures should contain no diagnostic medical information).

(d) The assessment method should cause minimal interference with other certification flight test activities. The technique should be appropriate for the specific phase and objectives of the certification program. Time constraints include the certification program schedule, production schedules, and delivery schedules.

(e) Cost associated with the workload measurement technique must be reasonable. Costs may include equipment, installation and preparation, time and schedule impact, flight and simulation, data reduction and analyses, and the documentation of the results.

(f) Equipment constraints include such factors as limited hardware space, limited panel space, a large distance between pilot and data collection hardware, potential signal interference, and the inability to change the flight deck configuration.

3.0 SUMMARIZE KNOWLEDGE ABOUT WORKLOAD MEASURES

In order to determine the optimal subset of workload measures to be tested in simulation a literature review was conducted. The intent of the workload literature review was to identify, collect, organize, and publish a cross referenced index of published articles which addressed the issue of workload measurement.

3.1 DESCRIPTION OF LITERATURE REVIEW

LITERATURE SEARCH

Using the keyword "workload" an electronic search was conducted of library data bases from McDonnell Douglas, the Boeing Company, NASA, the U.S. Air Force, and universities in the metropolitan Los Angeles area. Abstract searches generated a list of document titles which were then collected for evaluation. Only material published after 1978 was evaluated in the present effort.

Criteria were generated to facilitate discrimination of likely documents for detailed review. The articles were sorted according to the following criteria:

(a) Empirical data from flight test or simulation,
(b) Empirical data from laboratory experimentation,
(c) Review article,
(d) Theoretical article.

In addition to library literature searches, recognized workload assessment experts were contacted to assist in obtaining the most recent literature. The results of the literature search, and the expert summaries, were integrated into fact matrices.

3.2 DESCRIPTION OF FACT MATRIX DEVELOPMENT

Matrices were developed that cross-referenced workload measure by different types of validity and reliability. The first criterion for consideration was whether the technical paper dealt with workload as a primary, secondary, or adjunct topic. If the topic of the paper was not centered on workload measurement techniques the paper was dropped from the evaluation process. Each document which contained an investigation of workload as the primary topic was evaluated. The papers were evaluated for any investigation of the validity or reliability of the workload measures reported. Each paper received a second, independent, review to confirm the findings of the first reviewer.

More than 1400 titles were collected in the Literature Review. Of this number over 900 titles addressed workload as either a primary or secondary focus of study. Of that set 621 titles addressed the workload measures function and factors contained in FAR 25.1523 Appendix D. Of this number, 319 titles addressed workload measurement technique reliability, validity, or both. In final form the fact matrix document consists of an alphabetized list of all titles which contained workload measurement as a primary topic of empirical investigation.

The following is a list of the workload assessment techniques tabulated in the Fact Matrices:

SUBJECTIVE

(a) Subjective Workload Assessment Technique (SWAT)
(b) NASA Task Load Index (TLX)
(c) Workload Compensation Interference/Technical Effectiveness scale (WCI/TE)
(d) Modified Cooper-Harper
(e) Interviews
(f) Surveys
(g) "Other" subjective measures

PHYSIOLOGICAL

(a) Body Fluid
(b) Brain Activity
(c) Heart
(d) Lung
(e) Muscle
(f) Skin
(g) Vision
(h) Voice
(i) "Other" physiological

PERFORMANCE

(a) Performance Primary Task: Time
(b) Performance Primary Task: Position
(c) Performance Primary Task: Event
(d) Performance Normal Secondary Task: Time
(e) Performance Normal Secondary Task: Position
(f) Performance Normal Secondary Task: Event
(g) Performance Artificial Secondary Task: Time
(h) Performance Artificial Secondary Task: Position
(i) Performance Artificial Secondary Task: Event

The Fact Matrix is presented as Volume 2 of Workshop One (Biferno and Boucek, 1987). The fact matrix is organized into three sections. First, is a list of the articles contained in the fact matrix organized alphabetically by first authors last name. Second, is a list of all the titles, in the order they were collected, contained in the fact matrix with the corresponding reference number. Finally, the cross reference of measure, by Appendix D function or factor, by reliability and/or validity are presented in the fact matrices. The numbers within the matrix cells (Table 3.2-1) are the database reference numbers which are found in: "Proceedings Of The Assessment Of Crew Workload Measurement Methods, Techniques And Procedures: Volume II - Library References."

Table 3.2-1

Example of Page From Fact Matrix

FAR 25 Workload Factor 4a: Degree of Mental Effort

Measure	Validity			Reliability				Applicability
	Content	Construct	Predictive	Test retest	Split half	Alternate forms	Inter-rater	
Body fluid	408 615 616 726	408 521		725 726				
Brain activity	3 32 33 71 72 73 86 120 121 134 (1.2) 139 (2.3) 237 266 427 557 560 618 632 651 (2) 726 736 777 795	3 32 33 72 73 86 88 187 237 426 427 557 560 567 618 694 795	120 427 557	121 726		134 (1.2) 427 651 (1.2) 795		
Heart	3 13 15 16 29 66 67 117 130 (1) 134 (1.2) 135 151 161 175 184	3 13 15 16 29 66 67 115 130 (1.2) 135 151 161 175 187 217	15 16 66 67 175 184 247 261 283 286 407 (1.2.3) 459 538 742 758	726		134 (1.2) 184 217 283 286 407 (1.2) 459 653 (2A. 2B. 2C) 655 (2.3) 742 758 760	67	

F1167.37 R1db

4.0 WORKSHOP ONE (LONG BEACH, CA)

4.1 OBJECTIVES

Workshop number one was conducted in order to obtain agreement among workload experts regarding a candidate list of measures for simulation testing at the NASA-Ames Research Center. The criteria for determining the candidate workload measures was empirical evidence of validity and reliability.

4.2 ATTENDEES

Fifty workload experts attended the two-day workshop held in Long Beach, California. They came from a wide cross section of scientists who have expertise with workload measurement. The area of workload measurement expertise was divided into the familiar domains of subjective ratings, physiological recordings, and performance measures.

4.3 DESCRIPTION OF EVENTS

On the first day presentations were made by experts regarding "state-of-the-art" workload measures broken down by domain: Subjective Rating, Physiological Measures, and Performance Measures. Three experts from each domain made presentations in order to ensure unbiased representation of the domain.

On the second day the group was divided according to areas of expertise for further panel discussions. The objective of the panel discussions was to provide an independent review of the facts concerning the validity and reliability of workload measures. The attendees were asked to comment on the results of the literature review and participate by means of discussion. A free exchange of ideas was encouraged and documented. The questions put before the workshop for all participants to answer were:

(a) Given the workload types being considered for measurement in a transport environment, which measures are the most valid, reliable, and applicable?
(b) On what evidence do you base your opinion?

Each workshop attendee received a set of the matrices, one matrix for each of the applicable workload types mentioned in FAR 25.1523 Appendix D. The matrices were reviewed and modified by the experts. Each workshop participant reviewed and discussed:

(a) The results of the literature review,
(b) The criteria which was suggested for selecting candidate workload measures,
(c) The list of candidate workload measures which was proposed for further testing.

Suggestions were solicited for additional workload assessment techniques (not included in the matrices) to insure that all measures were considered.

A two volume summary of the proceedings was generated from the first workshop. Volume One contains the presentations given at the workshop summarizing the current state of the art in the field of workload assessment (Biferno and Boucek, 1987a). Volume Two contains a bibliography from the comprehensive literature review that was performed and the fact matrices (Biferno and Boucek, 1987b).

4.4 RESULTS OF WORKSHOP

The final list of candidate measures was influenced by the results of the workshop and constitute the workload measures which were considered the most valid, reliable, and applicable for certification. Workload measures suggested from the panel discussions, measures identified by Douglas and Boeing as candidates prior to Workshop One, and measures actually used in the Part-Task simulation are presented below (Table 4.4-1).

Timeline Analysis was used as an analytic tool in order to make a priori predictions regarding the task demands imposed on the crew. For a measure to be considered valid it must be able to discriminate between the levels of low and high workload operationalized by the task demands.

Table 4.4-1

RECOMMENDATIONDS OF PARTICIPANTS AT WORKSHOP ONE	DOUGLAS/BOEING TEAM RECOMMENDATIONS	ACTUAL MEASURES USED IN SIMULATION TEST
SUBJECTIVE	**SUBJECTIVE**	**SUBJECTIVE**
Subjective Workload Assessment Technique (SWAT) NASA - Task Load Index (TLX)	Subjective Workload Assessment Technique (SWAT). NASA - Task Load Index (TLX) Modified Cooper-Harper	Subjective Workload Assessment Technique (SWAT). NASA - Task Load Index (TLX) 1 to 20 Point Overall Workload Score
PHYSIOLOGICAL	**PHYSIOLOGICAL**	**PHYSIOLOGICAL**
Heart Rate Heart Rate Variability Eyeblink Rate Eyeblink Closure Duration	Heart Rate Heart Rate Variability Power Spectral Analysis Eyeblink Rate Eyeblink Duration Eyemovements Electroencephalogram	Heart Rate Heart Rate Variability EyeblinkRate Power Spectral Analysis (Blood Pressure & Respiration Components)
PERFORMANCE	**PERFORMANCE**	**PERFORMANCE**
• PRIMARY TASK	• PRIMARY TASK	• PRIMARY TASK
Control Activities Errors Performance Margins (RMS ERRORS)	Control Activities Glidescope & Localizer Error RMS Flight Director Error Attitude At Outer & Inner Markers	Control Activities Glidescope & Localizer Error RMS Flight Director Error Attitude At Outer & Inner Markers
• SECONDARY TASK		• SECONDARY TASK
Sternberg Task (AUDITORY & VISUAL)		Sternberg Task (AUDITORY)

5.0 DEVELOPMENT OF MISSION SCENARIOS

The mission scenarios used for evaluating a new aircraft flightdeck for workload requires careful consideration in order to manipulate task demands relevant to FAR 25.1523 Appendix D.

During the aircraft certification process the manufacturer provides a description of the flight scenarios for the simulation testing, flight test, or the "mini-airline" operation, for workload evaluation to the FAA. The level of detail for scenario description must be sufficient enough to allow for the discussion of the flightcrew actions that are to be evaluated in flight.

It is during high fidelity simulation, or actual operation, that workload measures provide information about the workload imposed on the crew in order to confirm that they can reliably cope when in airline service.

Seven mission scenarios were developed for the simulation testing portion of this contract effort. Four simulation scenarios were used in the Part-Task simulation testing: two short (30 minute) segments, a high and a low workload condition of each. Three simulation scenarios were used in the Full-Mission testing: two short (30 minute) segments and one long (1:30 minute) segments, and are reported in the Methods section of the Full-Mission simulation. Detailed descriptions of these scenarios can be found in the appropriate simulation design sections; 7.1.2.1 and 9.1.2.1, respectively.

5.1 SELECTION OF CRITICAL WORKLOAD EVENTS

A sampling of normal and non-normal procedures was implemented in the simulation scenarios to manipulate the task demands of the flight crew in order to vary workload. The face validity (realism) of the task demand manipulations was verified by flight operations personnel (from both Douglas and Boeing). Operating considerations such as weather, routes, weight, and balance were considered representative of actual B-727 operations. Malfunction conditions were selected that would exercise the functions and factors of FAR 25.1523 Appendix D, and would not be considered improbable events. Preplanned dispatch-inoperative items (i.e., Autopilot Inop) that could result in added workload were incorporated in the simulation program.

To determine that the high workload events to be used in the scenarios demonstrated face validity there was close coordination with flight operations personnel (from Douglas and Boeing) to ensure the following: malfunctions occurred in the scenarios at a logical time and phase of flight and required operationally correct responses from the crew; multiple failures occurred in a logical order and were representative of malfunctions experienced in airline operations. High workload events were also coordinated in the Air Traffic Control (ATC) scripts with ATC personnel.

The method of "triggering" the malfunction was planned so that the malfunction occurred consistently across evaluation flights.

5.2 SCENARIO DESCRIPTION

The following is a list of items essential for thorough scenario description. All the following items should be considered in the development of scenarios used in a certification effort.

5.2.1 WEATHER

A consideration for simulation testing is the weather conditions to be experienced during the evaluation. The weather conditions for the scenario should include both Instrument Meteorological Conditions (IMC) and Visual Meteorological Conditions (VMC). In addition, altimeter setting, winds, temperature, ceiling, visibility, and dewpoint need to be specified. The weather can then be developed for each of the airfields used in the scenario. Winds aloft, surface observations (ATIS), terminal forecasts should all be developed for the simulation test.

5.2.2 FLIGHT ENVIRONMENT

CLEARANCES AND ROUTING

As with all other aspects of flight operations, there must be face validity for the scenarios to be flown for workload evaluation. As departure and landing charts are periodically updated, either the simulation scenario must be revised for accuracy, or the scenario must be frozen to Standard Instrument Departures (SID) & Standard Terminal Arrival Routes (STAR) of specific dates, which are then supplied with the flight briefing material. The latter approach was used in this study.

Inoperative navigation aids, changes in 'typical' runways at an airport, diversions owing to weather, and missed approaches are all appropriate considerations for manipulations of workload for the purpose of simulation scenario specification.

FLIGHT PLANS

Flight plans should be provided for each route simulated. The flight plan includes distance to each waypoint, time between waypoints, and total elapsed time along the route. Flight plans must take into account required climb and cruise airspeeds, and ATC requested clearances and routes. From the flight plan a mission summary can be developed that includes more detailed events such as when the malfunctions occur.

DISPATCH RELEASE PACKAGES

Before flight, subject pilots should be given a dispatch release package which includes data representative of the information provided for a revenue airline flight. This includes a skeleton flight plan, route data, weather information, weight, and balance data, Notice to Airmen (NOTAMS), Convective Weather Information (SIGMETS), and known inoperative items complying with the Minimum Equipment List (MEL). The dispatch release packets used in the simulation studies are included in Appendix A.

AIR TRAFFIC CONTROL (ATC) SCRIPTS

Compliance, as well as attending to ATC direction is a significant source of workload for the commercial transport environment. ATC interaction with the flight crew should be incorporated in an evaluation of crew workload.

Included with the ATC script should be a list of frequencies used during the scenarios. Included in the list of frequencies are dispatch, clearance delivery, departure control, ATIS, tower (at the departure and arrival airports), enroute centers and approach control frequencies. The radio frequencies should be included in the dispatch release packages.

The ATC scripts used in the Full-Mission simulation testing performed at NASA-Ames (Appendix C) provide an example of the detail that was required for ATC simulation in the simulation testing environment.

The capability exists for full ATC support at the NASA Ames 727 simulator facility; therefore, ATC scripts had to be developed. ATC communications required by the scenario were integrated into the detailed scenario that was built.

During the simulation tests ATC communication, similar to revenue service, included many calls to 'other' aircraft in the ATC system in order to replicate "real world" conditions.

In addition, the visual system was programmed to support a percentage of the 'other' aircraft as visual targets in order to enhance simulation fidelity. The remainder of the ATC calls to 'other' aircraft did not include visual targets. To ensure that the ATC calls occurred at the same point in each flight during the simulation tests was a difficult task. The ATC personnel were provided operational cues (i.e., measurement window openings and closings) to aid in their attempt to make calls in a consistent fashion. The controllers used lights associated with data window `triggers' to aid in the timing of their interaction.

5.2.3 AIRCRAFT CONSIDERATIONS

WEIGHT AND BALANCE

Fuel and passenger loading calculations should be computed for each route including: gross weight at takeoff, fuel at takeoff, the amount of fuel burned, fuel remaining after landing, and the landing gross weight. This information affects takeoff and landing speeds, required runway lengths, and all aircraft performance characteristics.

PHASES OF FLIGHT

The phases of flight for the scenario should be specifically defined for data collection purposes, such as those described in the simulation design sections 7.1.2.1 and 9.1.2.1. The phases of flight used in the following simulation scenarios were of varying length, but incorporated the operational procedures associated with takeoff, climb, top of climb, cruise, top of descent, approach, and landing.

MALFUNCTIONS AND MINIMUM EQUIPMENT LIST (MEL) ITEMS

Malfunctions should be planned and coordinated so that they occur logically in the scenario and require operationally correct responses from the crew. The method of 'triggering' a malfunction should be planned so the malfunction occurs consistently across the subject population. Pilot deviation from course or altitude must be considered when specification of the malfunction is considered.

Dispatching the aircraft with allowable systems inoperative is another technique for manipulating workload. Autopilots or primary pressurization systems inoperative are candidate manipulations to vary task demands.

DATA COLLECTION WINDOWS

When collecting data for specific phases of flight during the workload evaluation scenario, defining the data collection periods (i.e., data windows) is very important. The method of 'triggering' the opening and closing of the windows must be chosen to cause the same events to occur in the same measurement window across the subject population. The windows should be triggered whenever possible by system defined events such as "flaps up" or the aircraft crossing a certain prescribed altitude during a profile descent. If operational events cannot be determined so as to preclude individual variation from flying performance, windows can be triggered by time events; for instance, a window can be closed 2 minutes after it opens. If a malfunction is planned, the window should be triggered to open prior to the malfunction.

DISTRACTION SCENARIOS

In addition to malfunctions, distractions were included in scenarios. When the same pilot flew the same scenario in test and retest, these distractors helped disguise the fact that the same scenario was being repeated. Examples of distractions used are shown below:

AUTO PRESSURE FAILURE (AFTER TAKEOFF, PASSING 4000 FT)

*F/E REPORTS, "AUTO PRESSURE CONTROLLER JUST FAILED. SWITCHING TO STANDBY."
*CAPT SAYS, "ROGER, IS STANDBY WORKING OK?"
*F/E SAYS, "STANDBY LOOKS GOOD. WE'LL OPERATE IN STANDBY THE REST OF THE TRIP."
*CAPT ACKNOWLEDGES.

PACK TRIP (AFTER TAKEOFF PASSING 3000 OR DESCENT PASSING 5000FT)

*F/E REPORTS, "WE HAVE A PACK TRIP ON THE RIGHT PACK."
*CAPT SAYS, "ROGER, SELECT A WARMER TEMPERATURE AND TRY A RE-SET."
*F/E ACCOMPLISHES PACK TRIP OFF CHECKLIST AND SAYS, "PACK RESET OK, CHECKLIST COMPLETE."
*CAPT ACKNOWLEDGES.

ELEVATOR FEEL DIFFERENTIAL LIGHT

*F/E REPORTS, "CAPT., THE ELEVATOR FEEL DIFFERENTIAL LIGHT IS ILLUMINATED. hYDRAULIC PRESSURES AND QUANTITIES OK. CHECKLIST SAYS TO FLY NORMALLY AND AVOID ABRUPT ELEVATOR INPUTS.
*CAPT ACKNOWLEDGES.

WINDOW OVERHEAT (AFTER TAKEOFF PASSING 4000 FEET OR DURING DESCENT PASSING 9000 FEET)

*F/E REPORTS, "CAPT., WE HAVE AN OVERHEAT ON THE R-1 WINDOW. I'LL TURN OFF THE SWITCH AND LET IT COOL, THEN WILL TRY A RE-SET.
*CAPT ACKNOWLEDGES.
*CAPT NOTES F/E TURN OFF R-1 WINDOW HEAT SWITCH.
*F/E REPORTS, "UNABLE TO RE-SET. CHECKLIST SAYS TO LIMIT AIRSPEED TO 200 FEET BELOW 10,000 FEET, AND TURN WINDOW DE-FOGGER ON."

*CAPT ACKNOWLEDGES AND NOTES F/O TURNING DE-FOGGER ON.

These distractions did not occur during data collection windows.

5.3 PROCEDURE USED TO CATEGORIZE OPERATIONALLY RELEVANT WORKLOAD WITH FAR 25.1523 Appendix D

To ensure the functions and factors of FAR 25.1523 Appendix D, are represented by the task demands used in testing a scheme is developed for mapping the functions and factors onto the tasks required by the mission scenarios. The goal is to evaluate the specific workload types (FAR 25.1523 Appendix D, functions and factors) with the appropriate crew complement during realistic operating conditions, including representative weather, air traffic, and airline operational duties.

The scenarios built for the simulation tests were based on the incorporation of operationally relevant types of task-demands being placed on the flightcrew. Flight scenarios were specified to include task-demands which pose a concern for transport flightcrew workload. An analytical assessment of these task-demands was accomplished using the Boeing Commercial Airplanes Time-Line Analysis (TLA).

Workload is thought to be a multidimensional construct combining the demands imposed on the pilot as he attempts to achieve the flight objectives, and the momentary capacity of the pilot to meet these demands. It is important that the workload evaluation scenario simulate a multi-faceted environment to provide a representative range of task demands for the subject pilots. While the tasks performed by the subjects in evaluation studies should be representative of those performed in actual flight operations, care should be taken to map the workload experienced in performing the tasks to the functions and factors of FAR 25.1523 Appendix D.

The task of operationally defining the functions and factors of Appendix D should include: Specification of the mission segments to be included in the evaluation, and development and implementation of a categorization scheme to map the specific tasks of the flightcrew to the functions and factors found in FAR 25.1523 Appendix D. A description of the process of mapping functions and factors to specific tasks follows.

Scenarios were constructed which described the flightcrew's actions down to the task and subtask level. A representative task is "tune VHF radio 1 to 123.9." Subtask description goes a step further such as, "move right hand to VHF radio 1 channel selector knob", "turn knob counter-clockwise to 123.9," "confirm frequency 123.9 is visible in display window," "return right hand to rest."

Each workload function and workload factor of FAR 25.1523 Appendix D, was assigned an operational definition. The operational definitions that were generated and used in this study are shown in Figures 5.3-1 through 5.3-4. Using these definitions assured consistency when mapping the functions/factors onto the tasks of the scenarios. The creation of the operational definitions included discussions with flight operations personnel from Douglas and Boeing. These rules could be defined differently with little consequence as long as they were used consistently in the mapping process. In fact, when two experimenters (one Douglas and one Boeing) independently assigned function/factor mappings to the steps of the scenarios using the pre-established definitions, their mappings were nearly identical. For the few differences that did exist, flight operations personnel were consulted and the differences reconciled.

Figure 5.3-1

Functions

1. Flightpath control
   - Anytime crew senses movement of the airplane (e.g., pilot senses airplane start to roll)
   - If the crew manipulates anything to cause any up-down or left-right motion

2. Collision avoidance
   - If navigating, and crew looks out window for anything
   - If ATC directs an action

3. Navigation
   - Any altitude or heading information
   - If Function 3 is assigned, Factor 8b must be used and Factor 5 cannot be used

A1167.19

Functions

4. Communications
   - Any verbal, incoming or outgoing speech, occurs
   - If Function 4 is assigned, Factor 8a must be used and Factor 5 cannot be used

5. Operations and monitoring of *aircraft* engines and systems
   - Visual confirmation of information
   - Manipulation of the aircraft (nonflightpath)

6. Command decisions
   - Anytime the pilot makes an action to manipulate the aircraft that requires a decision

A1167.20

Figure 5.3-2

Factors

1. Controls
   - Any manipulation of any aircraft control (e.g., switches)
   - If Factor 1 is assigned, Factor 5 cannot be used

2. Displays
   - Any visual confirmation or visual reference to an indicator showing the state of the aircraft (e.g., CRTs, dials, etc.)

3. Procedures
   - Any standard (normal) action for normal operation of the aircraft

5. Monitoring
   - The extent of required monitoring for normal aircraft operation
   - Factor 5 excludes the use of Factors 1, 8a, and 8b and Functions 3 and 4

A1167.17

Figure 5.3-3

Figure 5.3-4

Factors

8a. Communications
- Any Function 4 fires Factor 8a
- Factor 8a excludes the use of Factor 5

8b. Navigation
- Any Function 3 fires Factor 8b
- Factor 8b excludes the use of Factor 5

9. Nonnormals
- Broken down into Factors 9-1, 9-2, 9-3, 9-5, 9-8a, and 9-8b

6. Crew member out of area

7. Nonnormal conditions that require manual as opposed to automatic control of aircraft systems

10. Crew member incapacitated

A1167.18

An example of the function and factor mapping is shown in Figure 5.3-5. As shown, the functions and factors are not mutually exclusive. In fact, many steps of the scenarios represent three or more functions and three or more factors. By the pre-defined rules, the action, "calls, `gear up'", for example, represents functions 4, 5, and 6 (communications, operations and monitoring of aircraft engines and systems, and command decisions, respectively) and factors 3 and 8A (procedures and communication, respectively). The level of task specification done for the scenarios can also be seen in the task listing included in Appendix B. In a 20 second period of time, six independent tasks are performed, each representing a variety of functions and factors.

The mapping procedure assured that a priori predictions of workload differences could be made prior to collecting data using the workload assessment techniques in the simulation at NASA-Ames. Measurement periods within the flight could be identified where workload levels were high or low. Function and factor tally sheets were prepared for each of the scenarios indicating frequency counts for the number of occurrences of each function and factor. An example tally sheet is shown in Figure 5.3-6.

To operationalize the differences between mental and physical workload, each function and factor was assigned to either mental or physical. No task is purely physical or purely mental; however, the assumption was made that tasks do lie along a continuum from pnysical to mental workload, and therefore, the task could be assigned to the end of the continuum that more closely described it. This procedure allowed physical and mental task loadings to be made for each phase of flight, for every scenario. Mental workload increases with mediational tasks such as perception, cognitive processing, and decision making. Physical workload increases with gross motor movement. In this manner, it could be judged which measurement periods contained relatively high levels of mental workload and which involved predominantly physical workload.

Function and Factor Mapping

Example

Time	Function	Factor	Activity
00:02:15			Gear Retract - Start Initial Climb
	4,5,6	3,8A	• Calls, "gear up"
	4	8A	• Hears F/O, "gear up"
	5	5	• Sees F/O compliance (peripheral vision)
	1,5	2,3,5	• Looks to see if airspeed stabilized at approximately V2 + 10
	1,5,6	1,2,3	• Adjusts pitch attitude to maintain V2 + 10 if necessary
	1,5,6	1,2,3	• Sets FD pitch knob to proper pitch attitude
00:02:35			Cleared Direct Sacramento Vortac

A1167.09

Figure 5.3-5

Part-Task Simulation

Function and Factor Tally Sheet

Flight Segment SFO → SCK

Window Cruise 2

Function

Function	Tally
1. Flightpath	1
2. Collision avoidance	2
3. Navigation	0
4. Communication	15
5. Operations and monitoring	3
6. Command decisions	2

Physical 11

Mental 50

Factor

Factor	Tally
1. Controls	0
2. Displays	0
3. Procedures	1
4. x x x x x x x x x x x x x x x x	
5. Monitoring	0
8a. Communication	2
8b. Navigation	0

Non-Normals

Non-Normals	Tally
7. Automatic	13
9(1) Control	3
9(2) Display	0
9(3) Procedure	6
9(5) Monitoring	0
9(8A) Communication	13
9(8B) Navigation	0

D1167.10

Figure 5.3-6

6.0 ROLE OF TIME-LINE ANALYSIS

The analytical measure used to predict, a priori, levels of workload was Timeline Analysis (TLA). TLA computes the ratio of time required, that is, execution time, to time available throughout a mission scenario (Miller, 1976). A serious criticism of TLA is the serial approach it takes in calculating task execution when it is known that pilots can conduct multiple actions in parallel. Flaws in the method leads to an over-estimation of workload, an error on the side of safety which is appropriate when evaluating a new aircraft. Boeing Commercial Airplane's TLA technique was used in this study because of the database available for the B-727 aircraft which was the testbed for the simulation studies.

6.1 OBJECTIVE

The timeline analysis was used to identify high and low task demand levels. A detailed task timeline analysis was performed on the flight scenarios to be used in the simulation testing at NASA-Ames.

6.2 DESCRIPTION OF TLA TASK

Timeline analysis uses micro-motion analysis techniques to compute a ratio of time required to complete tasks to the time available. Timeline analysis breaks down the ratio of time required to time available for different body channels (i.e., vision, manual left & right, auditory, cognitive, and verbal). To support the Boeing Timeline Analysis program it was necessary to build a geometric data base describing the flight deck of the NASA-Ames 727 simulator. The simulator is a Delta configuration 727 series 232. The geometric data base file contains control and instrument descriptions and locations and related information. It contains airplane coordinate locations of the flightdeck instrument panels and the rectangular coordinates of the controls and indicators on each panel. These coordinate locations are based on engineering drawings of the cockpit and allows the flight deck to be evaluated from any angle (Figures 6.2-1, 6.2-2, and 6.2-3).

Time based mission scenarios were built describing the crew activity associated with flying the routes used during testing at NASA Ames. Creation of the scenario is based upon data derived from mission flight plans, maps, approach and landing charts, interaction with ATC, aircraft performance data and aircraft operations manuals. Using this information base, detailed procedures were developed which defined the actions a crew member must accomplish to successfully complete a mission (Figures 6.2-4). These procedures establish the basic work time units from which the TLA workload statistics were derived. Normal as well as high workload procedures were developed for the routes.

TLA represents workload requirements for various body channels including: Visual, manual (left, right, and both), verbal, auditory and cognitive. Execution time estimates are calculated in terms of hand and eye motions used to execute a procedure and the time in transit required to accomplish these motions (Figure 6.2-5). Manual motion is calculated from one control to the next along a curve to simulate lifting the hand from one control, moving it in an arc to the next control and lowering the hand. Dwell times required to use a specific control or display are selected from stored data tables. Summing the transit and dwell times for each action produces an estimate of the total time required by an operator to successfully complete the procedure.

In the geometric data base each device on the flight deck is characterized in terms of it's location, dwell time, and complexity score (Figure 6.2-6). This device complexity score is based upon the information content of the possible states the device presents (Figure

Figure 6.2-1

Flight Deck Geometric Data Base

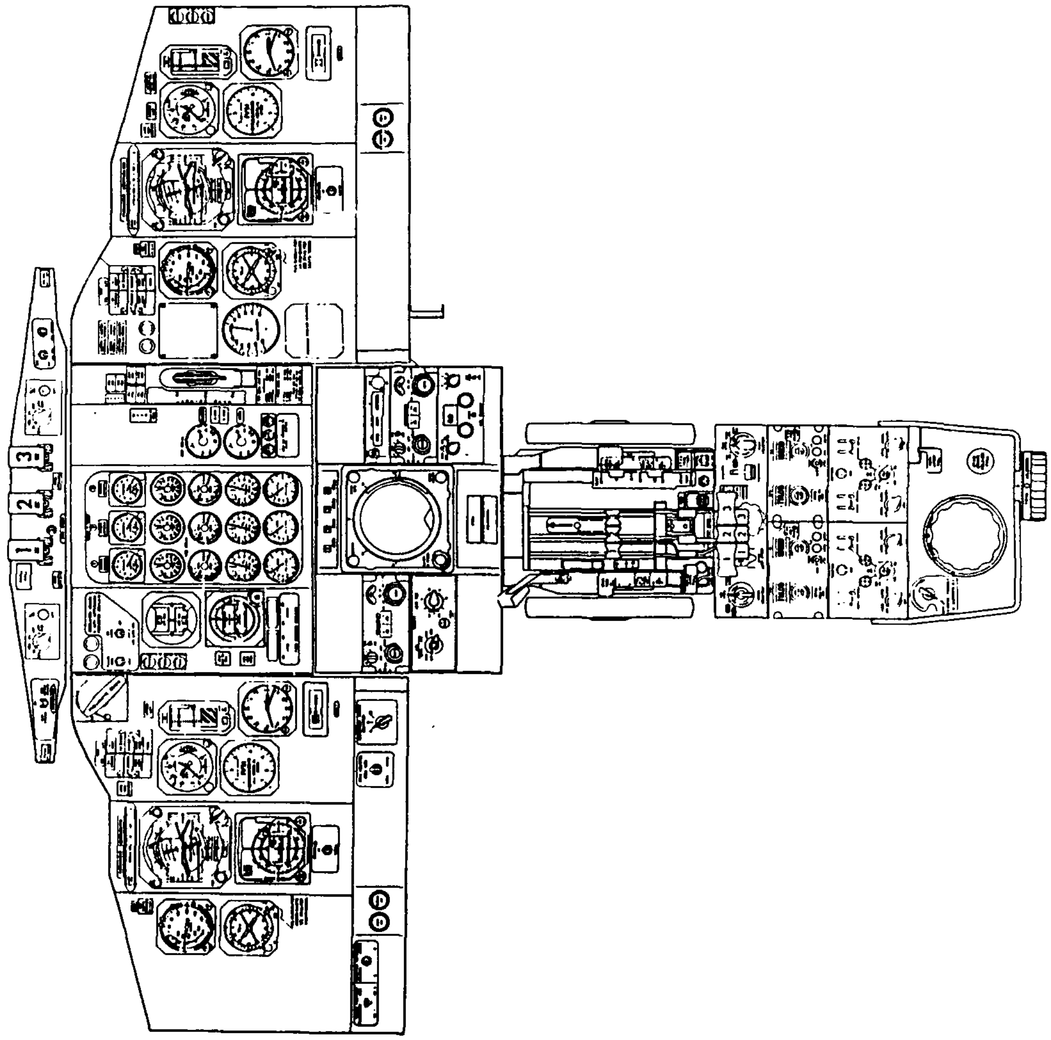
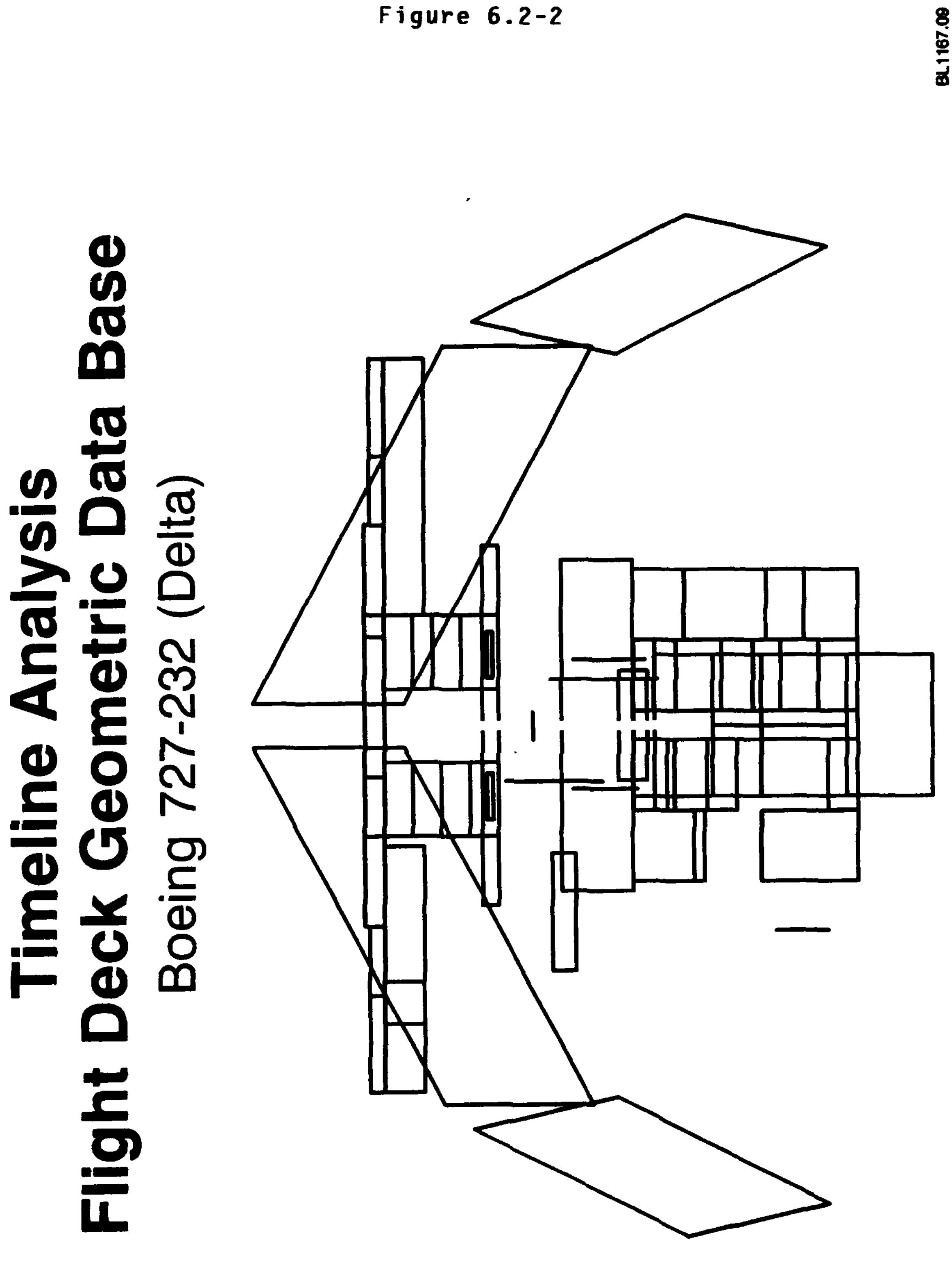


Figure 6.2-2


Timeline Analysis
Flight Deck Geometric Data Base
Boeing 727-232 (Delta)
BL1167.09

Timeline Analysis

Example of Flight Mission Scenario File

CR	1 Captain			
FP	1 Takeoff			
PR	0001.30	Start takeoff run	0001.30	0001.45
ST				

- Hears brake lever release
- Senses airplane start to roll
- Advances thrust levers for number 1 engine for initial acceleration and allows even engine spoolup
- Advances thrust levers for number 2 engine for initial acceleration and allows even engine spoolup
- Looks at engine EPR indicators for even engine acceleration (engines 1, 2, and 3)
- Continues thrust levers to approximate takeoff setting (engines 1, 2, and 3)
- Check engine EPR indicators for takeoff bug setting (engines 1, 2, and 3)
- Sees F/O adjust thrust levers for number 1, 2, and 3 engines

AL1167.35

Figure 6.2-3

Timeline Analysis (Continued)

Example of Flight Mission Scenario File

- Looks through left front window along runway centerline
- Maintains light forward pressure on column
- Keeps wings level
- Hears F/O "80 kn"
- Looks at airspeed display
- Says, "Check"
- Continues looking out forward window

CD 8101,13201,7104,7204,239,235,7111,7211,239,235,7111S,7211S,13302,180, 13302,30004,114,20004,13302

PR 0001.53 Rotation 0001.46 0002.05

ST

- Hears F/0 "V one"
- Hears F/O, "Rotate"
- Looks at airspeed
- Begins to apply back force on control wheel
- Rotates to liftoff attitude
- Complete rotation to desired attitude with reference to attitude indicator
- Senses liftoff
- Checks altimater for positive rate of climb

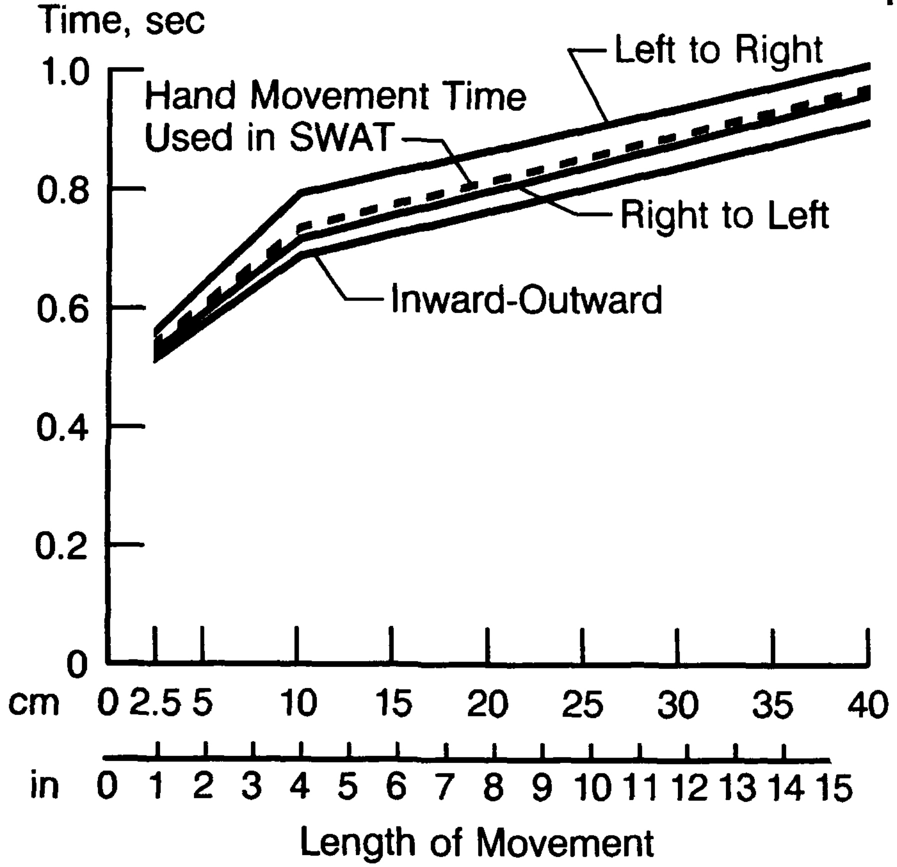
AL1197.36

Figure 6.2-4

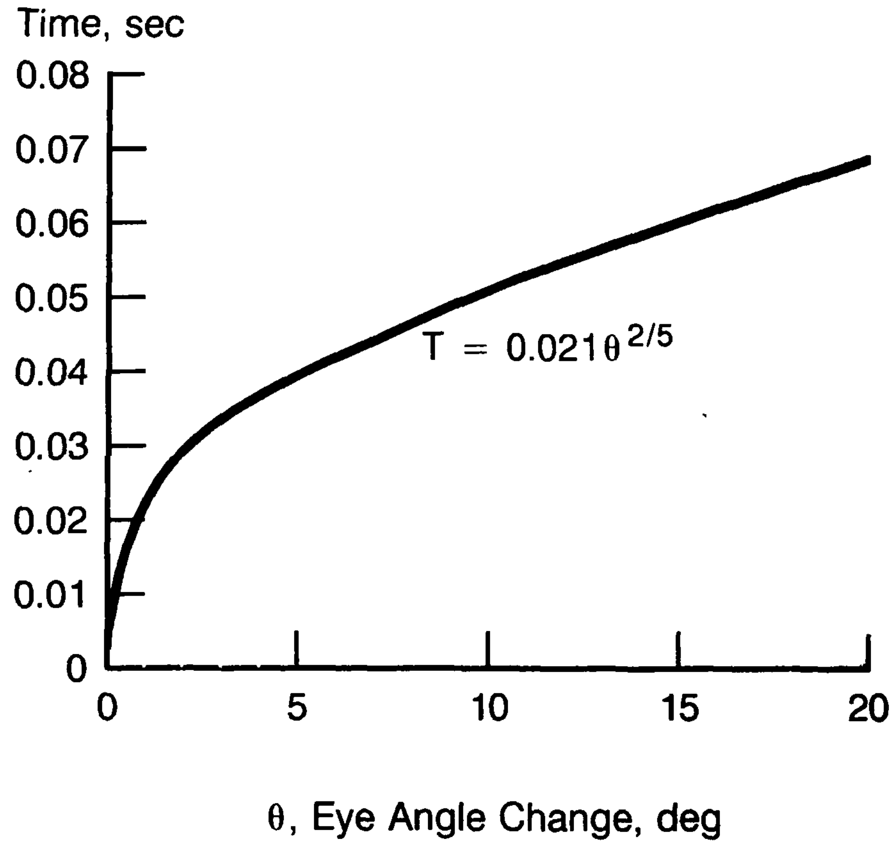
This page intentionally left blank

Timeline Analysis

Time Requirements



Horizontal Positioning Movements Versus Length of Movement



Eye Motion Versus Angle-of-Eye-Movement Change

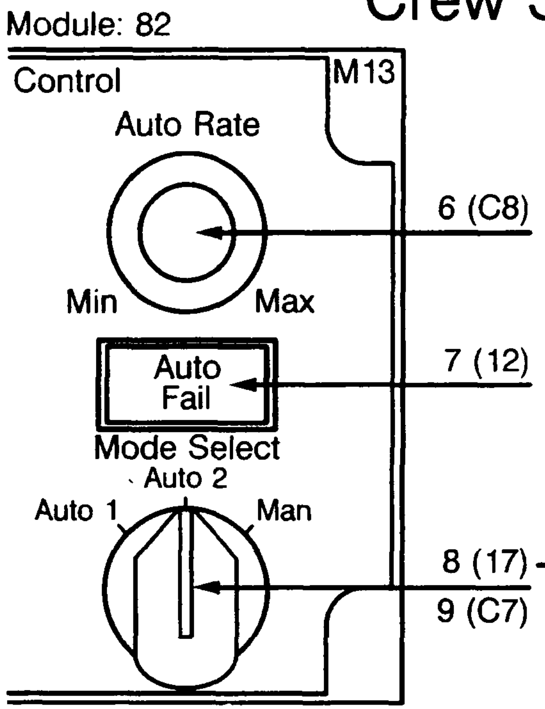
BL1167.07

Figure 6.2-5

Figure 6.2-6

Timeline Analysis

Crew Station Description, Example



Each device is characterized in terms of its:

- Aircraft location
- Workload cost (dwell time)
- Complexity score

Workload Cost Table (Example)

Estimated Workload Cost (Dwell Time, sec)		Workload Type Code
4.04	CIRCULAR SCALE GAUGES (QUANTITATIVE READING)	13
3.30	CIRCULAR SCALE VALVE POSITION	14
3.67	LINEAR SCALE	15
1.50	DIGITAL INDICATOR	16
0.75	MONITOR SWITCH POSITION	17
2.73	CIRCULAR SCALE GAUGES (QUALITATIVE READING)	18

Example Data Card Format

8208	1 7	2.20 0.38	1.58	PRESSURE MODE SEL MONITOR
Device Code Number	Workload Type Code	Location Coordinates	Complexity Score (bits)	Device Description

BL1167.04

6.2-7). It serves as the basis for estimating cognitive workload. The procedure complexity is the sum of the device complexity scores for all steps of the procedure.

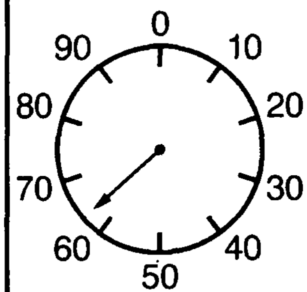
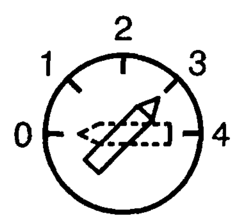
Cognitive workload is computed by an algorithm that relates the complexity score to the number of choices. The algorithm calculates how long it takes a person to act depending on the number of choices available. Verbal and auditory response times were derived from data contained in the *Index of Electronic Equipment Operability.*

Workload estimates are made for each task, procedure, phase of flight, and for the entire scenario. Analyses were completed only for the captain's tasks.

Figure 6.2-7

Timeline Analysis

Device Complexity Measure

Definition	Examples
Device complexity is the number of binary digits required to encode the possible number of alternatives associated with the device	 Instrument Reading Number of Alternatives $= \dfrac{\text{Range}}{(0.5)(\text{Scale Unit})}$ Device Complexity $= \text{Log}_2 \dfrac{10}{(0.5)(1)} =$ 4.35 bits
Device Complexity $=$ Log_2(Number of Alternatives) bits	Rotary Selector Switch  Discrete Control Number of Alternatives $=$ 5 Device Complexity $= \text{Log}_2\ (5) =$ 2.32 bits

BL1167.01

7.0 PART-TASK SIMULATION TESTING

The Part-Task simulation was performed at the NASA-Ames Research Center, Moffett Field, California. To ensure the generalizability of the test results to the real world, the Part-Task testing environment was as similar to the operational environment as possible (e.g., the flight deck of the production aircraft during certification flights).

7.1 METHOD

Only Captains were used for the following evaluation. Newer aircraft, with two crew flightdecks, do not have the wide variety of tasks found in older flightdecks. The newer generation, two crew aircraft, normally divide the responsibilities so that one crew member is considered the Pilot Flying (PF) and the other is the Pilot Not Flying (PNF). The PF controls the aircraft, either manually or using the autopilot, has primary responsibility of the navigation of the aircraft, and monitors the aircraft systems. The PNF handles communications, is the primary system monitor, and serves as a backup for the navigation process. The Captain and First Officer exchange these roles readily. For this reason it was deemed sufficient to instrument and record workload from only the pilot in the left seat in the following study. No attempt was made to address crew performance when PF and PNF duties are exchanged, for a thorough discussion see Orlady (1982).

7.1.1 SUBJECTS

PILOTS

Eighteen Airline Transport Pilots (ATP), (from American, United, Delta, TWA, and Eastern) served as subjects in the experiment. Subjects were all male ranging in age from 44 to 58. Subjects were either currently F.A.R. Part 121 qualified as Captain for the B-727 or had spent 5 years of duty as Captain for the B-727.

CONFEDERATE FLIGHT CREW

Two confederates participated in the simulation study as the First Officer and Flight Engineer. Preston Sult, a member of Flight Crew Training at Boeing Commercial Airplanes, served as the First Officer in the study. Preston also gave the briefing for differences training and the routes to the pilots participating in the study. Michael Bortolussi, Western Aerospace Inc., served as the Flight Engineer in the study. Both the First Officer and Flight Engineer were cognizant of the workload manipulations, and attempted to give each pilot similar treatment during the simulation.

7.1.2 EXPERIMENTAL DESIGN

The factors that drove the design included:

(a) Different levels of workload as defined by the functions and factors of FAR 25.1523 Appendix D,
(b) Two test sessions in order to evaluate reliability,
(c) Sampling of various phases of flight in order to represent task demands representative of operational conditions.

7.1.2.1 INDEPENDENT VARIABLE

TEST/RETEST

The method employed in the present study utilizes Test/Retest as a means of determining the reliability of the various workload measures. This meant that the pilots involved in the study participated on two separate occasions. The period between the two simulation test periods was at least 10 days, and was as high as 42 days in one case.

LOW AND HIGH WORKLOAD LEVELS

There were two different levels of workload: low and high. The low workload flight is a `nominal' flight, no equipment is MEL, the weather is clear with light winds. The high workload flight contains Instrument Meteorological Conditions (IMC) and the winds aloft are stronger. Also in the high workload flight malfunctions are encountered. At the top of the climb segment the Number three engine fails, and 3 minutes later the "B" system hydraulic system loses quantity and pressure resulting in a total failure. The autopilot is INOP in the high workload flight as well.

A table is provided that contains a summary of the workload manipulations in order to aid the reader in understanding the different task demands for the low and high workload flights (Table 7.1.2.1-1).

The manipulation of workload, low and high, and flight routes, San Francisco to Stockton and Sacramento to San Francisco, were counter-balanced across subjects.

PHASES OF FLIGHT

Seven phases of flight were examined in the simulation test:

(a) Takeoff
(b) Climb
(c) Top of Climb (TOC)
(d) Cruise
(e) Top of Descent (TOD)
(f) Approach
(g) Landing

Each flight contained seven measurement "windows" to assess the seven different phases of flight. The term window is used to give the idea of a momentary examination of a portion of a well defined phase of flight. Window and phase of flight are used synonymously. Window is used when referring to experimental design or measurement period, while phase of flight is used when discussing results. The events which opened and closed the windows is listed below:

Table 7.1.2.1-1

Two Workload Levels

Conditions	Level	
	High	Low
Weather	Ceiling, 500 ft; visibility, 1 mi	Clear
Wind	12 kn at takeoff and landing	5 kn at takeoff and landing
Autopilot	Inoperative	Operating
Turbulence	Significant	Minimal
Nonnormals	• Number three engine stall • Hydraulic System B failure • Distractors (i.e., autopressure failure, window overheat)	None

AL1167.04

PHASE OF FLIGHT	OPENING EVENT	CLOSING EVENT
(a) TAKEOFF	E.P.R. > 1.5	Flaps 5 degrees
(b) CLIMB	Flaps up	1 Minute later
(c) TOP OF CLIMB	10,000 feet	2 Minutes later
(d) CRUISE	3 Minutes after 10,000 feet	2 1/2 Minutes later
(e) TOP OF DESCENT	Throttles to idle	5,500 feet
(f) APPROACH	Localizer Activation	Outer Marker
(g) TOUCHDOWN	Middle Marker	1 1/2 Minutes later

A graphic is provided to illustrate the flight scenarios pictorially in order to aid the reader in understanding the measurement windows (Figure 7.1.2.1-1).

7.1.2.2 DEPENDENT VARIABLE

SUBJECTIVE RATING

The Subjective Workload Assessment Technique (SWAT), NASA-Task Load Index (NASA-TLX), and a simple 1-to-20 point overall workload score were used for subjective workload assessment.

Half of the subjects used the Subjective Workload Assessment Technique (SWAT) (Figures 7.1.2.2-1 and 7.1.2.2-2) and the other half used the NASA Task Load Index (TLX) (Figures 7.1.2.2-3 and 7.1.2.2-4) with the 1-to-20 point overall workload scale appended to the bottom of the NASA-TLX rating page.

In the current paradigm, the implementation of the subjective rating technique was not possible in-flight due to the contamination of the other measures. Owing to the recording of control input activity it was decided to be inappropriate to hand the pilot a paper and pencil based subjective rating technique. To assess the subjective workload tools (SWAT and NASA-TLX) half of the subjects received SWAT, the other half received the NASA-TLX, during post-flight videotape viewing. An attempt made to gather subjective ratings closer in time to the actual flights. Shortly after landing the pilots were handed a clipboard with four segments to the flight demarcated: (1) takeoff through top of climb, (2) Cruise, (3) top of descent through approach and landing, and (4) an overall rating for the entire flight. Those results are discussed in another publication (Battiste and Bortolussi, 1988).

Both SWAT and the NASA-TLX require techniques to customize the event ratings so they can be combined to yield a single 0-to-100 scale for each measurement window. Utilizing conjoint measurement techniques the 0-to-100 score for SWAT is based on an interval scale. The technique used to customize the NASA-TLX 0-to-100 score does not yield a truly interval 0-to-100 scale in a statistical sense, but it will be treated as such in the analyses.

Figure 7.1.2.1-1

Phases of Flight and Data Collection

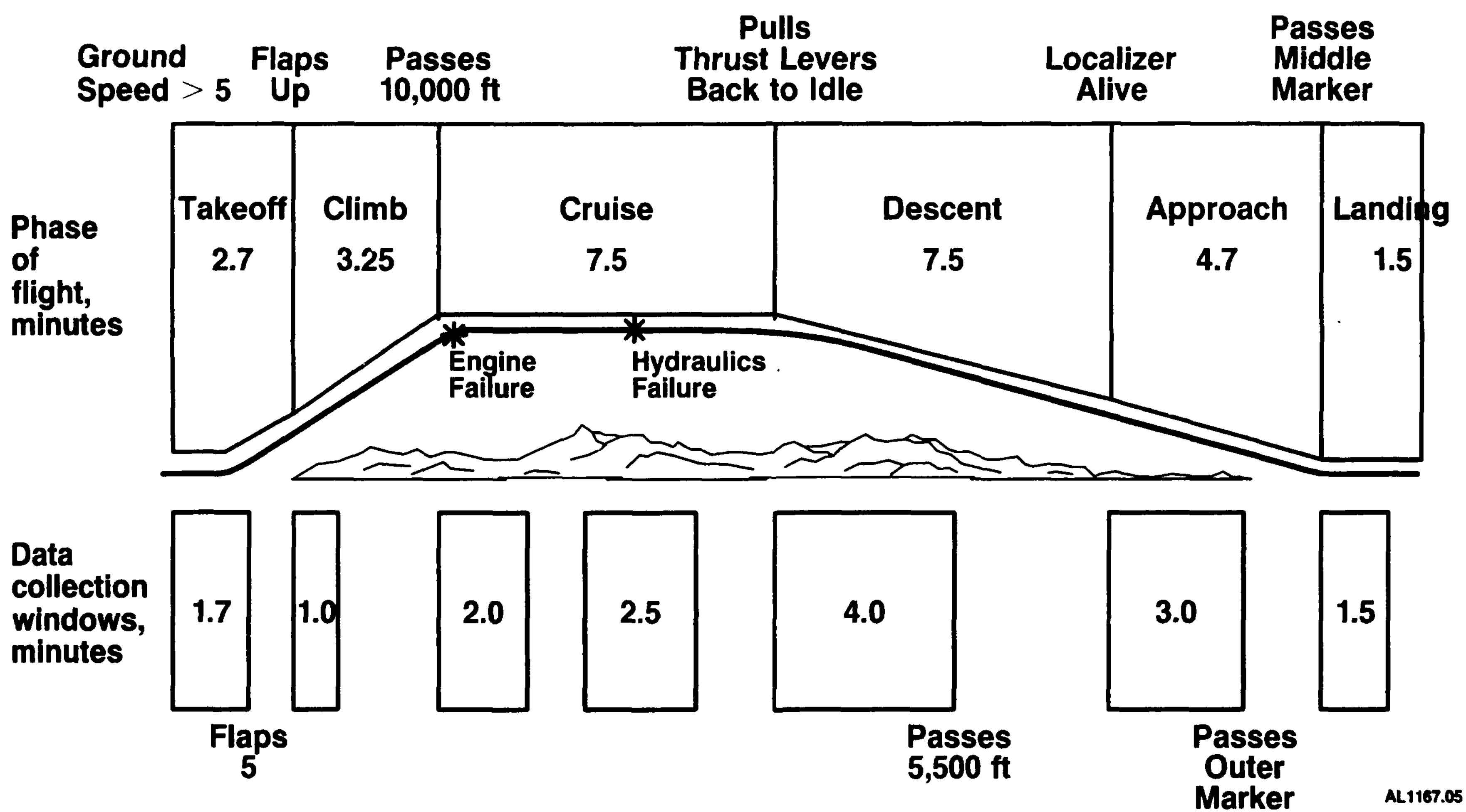


Figure 7.1.2.2-1

SWAT Rating Scale

Subject No.__________

Date __________

Mission Segment __________

I. Time load

__ 1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

__ 2. Occasionally have spare time. Interruptions or overlap among activities occur frequently.

__ 3. Almost never have spare time. Interruptions or overlap among activities are very frequent or occur all the time.

II. Mental effort load

__ 1. Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

__ 2. Moderate conscious mental effort or concentration required. Complexity or activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

__ 3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

III. Psychological stress load

__ 1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

__ 2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

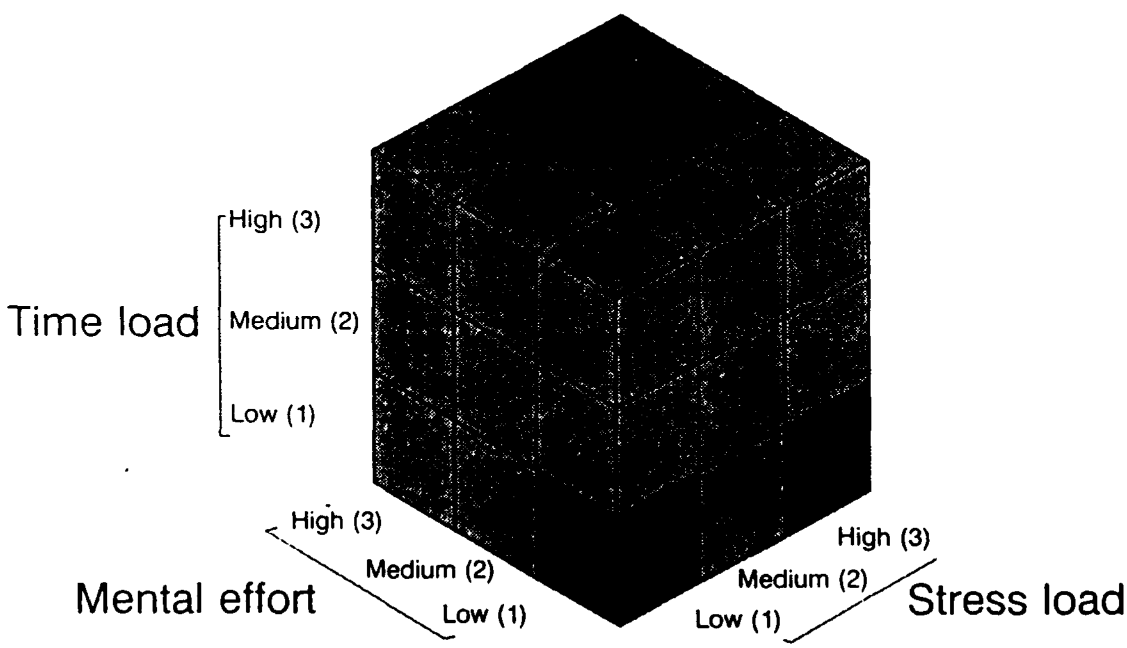
__ 3. High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self control required.

F1167.34A R2db

Figure 7.1.2.2-2

SWAT

27 Different Combinations



F1167.35

Figure 7.1.2.2-3

TLX Rating Scale Definitions

Title	Endpoints	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Perfect/Failure	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

F1167.32 R3G

Figure 7.1.2.2-4

NASA TLX Rating Scale

Subject ID:________________Task ID:________________

Rating Sheet

Mental demand

Low High

Physical demand

Low High

Temporal demand

Low High

Performance

Good Poor

Effort

Low High

Frustration

Low High

Overall workload

Low High

F1167.36 R1db

SWAT requires a rating of 1, 2, or 3, corresponding to low, medium, or high on each of the dimensions (time, mental effort, and stress) for each measurement event. Using conjoint measurement techniques, SWAT ratings can be converted to the 0-to-100 interval score. SWAT requires a sort, from low to high, of the 27 different cards containing all the possible combinations of time, mental effort, and stress dimensions. The card sort is completed before the event scoring begins. The card sort provides the necessary information for the conjoint scaling solution that allows assigning the 0-to-100 score for the event ratings, 1-1-1 through 3-3-3. A given event rating, such as 2-1-3 (medium rating on time, low rating on mental effort, and high rating on stress), can then be converted into a score that has a value ranging from 0-to-100.

The NASA-TLX uses six, 20-point low to high, bipolar scales for mental demand, physical demand, temporal demand, performance, effort, and frustration. The customizing portion, weighting, of the NASA-TLX was applied after the event scoring. The weighting is done to establish a priority among the dimensions in a quantitative fashion. The weights are ranked in order of importance by a forced-choice paired comparison task. The weights are combined with the event ratings to form the 0-to-100 combined workload score.

All of the subjective ratings were collected post-flight, utilizing video tape. Each simulation flight was video taped. The video tape recorded a quad image which contained: (1) right side profile of Captain, upper left of quad image, (2) left side profile of First Office, upper right of quad image, (3) left three-quarter view of Flight Engineer panel, lower left of quad image, and (4) view forward of flight deck from pedestal, lower right of quad image. Subjects viewed the video tape at the end of a day's session for the purpose of making subjective ratings. To demarcate the measurement windows small light emitting diode (LED) lights visible in the video tape were illuminated during the measurement windows. The LED lights are out of the pilot's field of view during the actual simulation runs. For the purpose of making subjective ratings the pilots were asked to attend to their workload when the LED lights where illuminated. When the measurement window closed, the lights were extinguished, the video tape was stopped by the experimenter, and the subject was asked to make event ratings. The pilots were instructed not to refer to previous ratings when making event ratings.

PHYSIOLOGICAL INSTRUMENTATION

Data was collected for horizontal and vertical eye movement, eyeblink rate, heart rate, and heart rate variability.

The pilots had electrocardiogram (ECG) electrode leads applied to the chest to record heart rate. Conventional stress-type hospital grade disposable silver-silver chloride electrodes were used. Since only the peak of the R-wave was relevant, not the complete ECG wave form morphology, placement was mainly dictated by considerations of convenience. One lead was placed just above the sternum and another was placed approximately four centimeters above the waist and ten centimeters to the left of the sagital plane.

Electrodes to record the electro-occulogram (EOG), including eyeblinks, were placed in a conventional manner: active and referent just beyond the outer canthus of the left and right eyes to record horizontal movements, and active and referent above and below the left eye to record vertical eye movements and eye blinks. Pilots were instrumented with Beckman 11mm Silver-Silver Chloride mini-cup electrodes, held on by adhesive collars. Methyl cellulose was used as the electrode cream. Linked mastoids leads served as the ground.

Resistance readings were checked for all the leads. Electrode leads were allowed to have a maximum resistance of 30 Kohms.

All the leads to the electrodes were connected to a Grass Instruments isolator electrode board (Model IMEB2). The connector box was suspended on the pilot's chest by cords which were tied around his neck and waste. The subjects reported that the isolator box did not interfere with their flight deck activities.

A 25 foot long Grass Instruments cable led from this box to the array of Grass amplifiers and power supply, which were in a 19 inch rack cabinet fastened to the back wall of the simulator cabin. The heart signal was amplified by a Grass model 7P511 AC amplifier and the two EOG signals were amplified by two model 7P122 DC amplifiers. These three physiological signals, along with an event marker signal and the audio from a microphone on the subject's label, were all recorded on a Hewlett Packard model 3968-A 8 channel FM tape recorder. The tape speed was 3 3/4" per second.

The tape recorder was under computer control. The computer would activate the FM tape recorder when a measurement window opened, and then stopped the recording when the measurement window closed.

The data collected during the simulations was subsequently played back in the laboratory for reduction and analysis.

EYEBLINKS

The analog signals for both vertical and horizontal eye movement were printed out on strip charts, from which raters "scored" the vertical record to determine the number of eyeblinks (Figure 7.1.2.2-5). Two scorers were used, and an objective scoring criteria developed, to insure a between scorer agreement of at least 95%. Determining the time elapsed between the opening and closing of each window made it possible to compute eyeblink rate in blinks per minute.

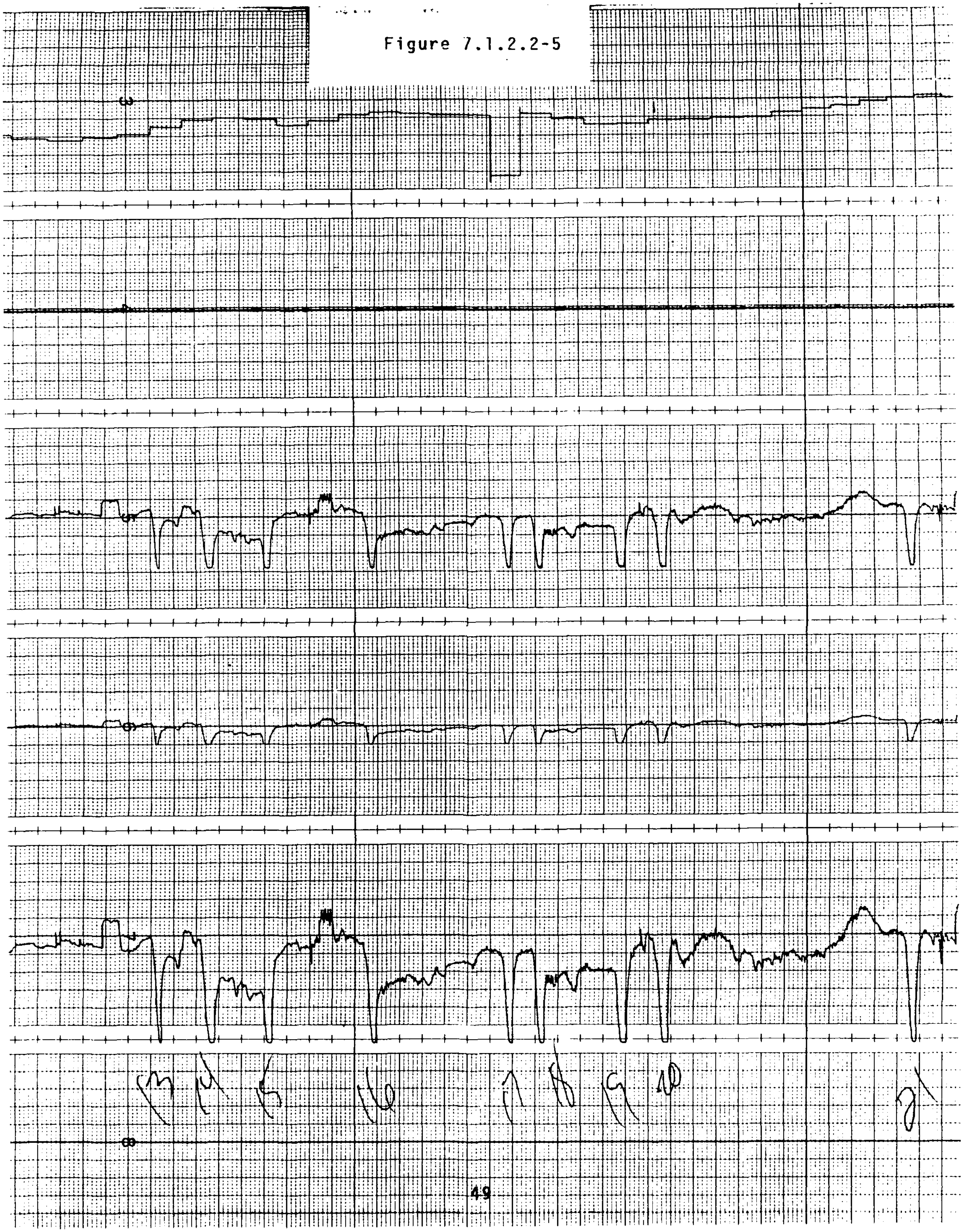
HEART RATE

Interbeat interval is a measure of the time elapsed between heart beats, whereas heart rate refers to how many beats occur in a minute. The analog heart signal waveform was examined for inter-beat interval scoring. A voltage sensitive Schmitt trigger, connected to a MINC (Digital Electronic Corp.) minicomputer, was used to digitize the analog record by timing and recording the duration of the intervals between successive "R-waves" of the cardiac signal in milliseconds. For each window all the heart inter-beat intervals (IBI's), in msecs (milliseconds), were saved as computer files for later processing and analysis.

Heart rate, in beats per minute, can be computed using the following formula: (1000 / R-R Interbeat interval) * 60. The transformation of the IBI to beats per minute is non-linear. The ordinal position of the phases of flight ranked by workload would remain the same, but the transformed scores would not correlate perfectly.

Occasionally heart data was contaminated by movement artifacts. It would result in IBI values significantly different with the pattern of IBI values collected in the same measurement window. A simple filter in the software excluded IBI values 33% different than the low and high IBI values considered to be valid within a measurement window.

Figure 7.1.2.2-5



HEART RATE VARIABILITY

A variety of methods have been suggested to index heart rate variability. However, as there is no consensus agreement in the field upon any one best way, and since the simple heart rate standard deviation has often been used for this purpose, we elected to utilize it as a measure of the heart rate variability.

POWER SPECTRAL ANALYSIS

A power spectral analysis of the heart record was also conducted using software provided by Randall Harris and Allen Pope of NASA-Langley. Fourier analysis of the low-pass filtered cardiac event sequence provided a spectrum of frequency components in the range of 0 Hz to 0.5 Hz. Two bands of energy from the spectrum were examined, the bands were 0.05 Hz to 0.15 Hz and 0.20 Hz to 0.40 Hz. The area between 0.05 and 0.15 is believed to reflect changes in blood pressure, and is predicted to decrease when the pilot is engaged in a cognitive task (Mulder, 1977). The area between 0.20 Hz and 0.40 Hz is believed to reflect changes in respiration (Mulder, 1977).

PERFORMANCE DATA

Data from the simulator was collected during the measurement windows as well. Wheel, column, pedal, and throttle position data was collected in order to compute control input activity. In addition, altitude over the outer and middle markers, flight director deviation, glideslope and localizer deviation, and lateral deviation from runway centerline were collected in the Approach and Landing windows. All performance data was collected at a rate of 10 Hertz (Figure 7.1.2.2-6).

Root Mean Square error of flight director deviation, as well as localizer and glide slope deviation could not discriminate between low and high workload, nor did the measures demonstrate any evidence of reliability. The piloting task in commercial aviation has large tolerances in the precision required in the flying task (e.g., plus or minus 300 feet at altitude). Using RMS tracking error measures as indices of workload would require the pilots to fly with a level of precision not normally required in revenue service.

CONTROL INPUT ACTIVITY

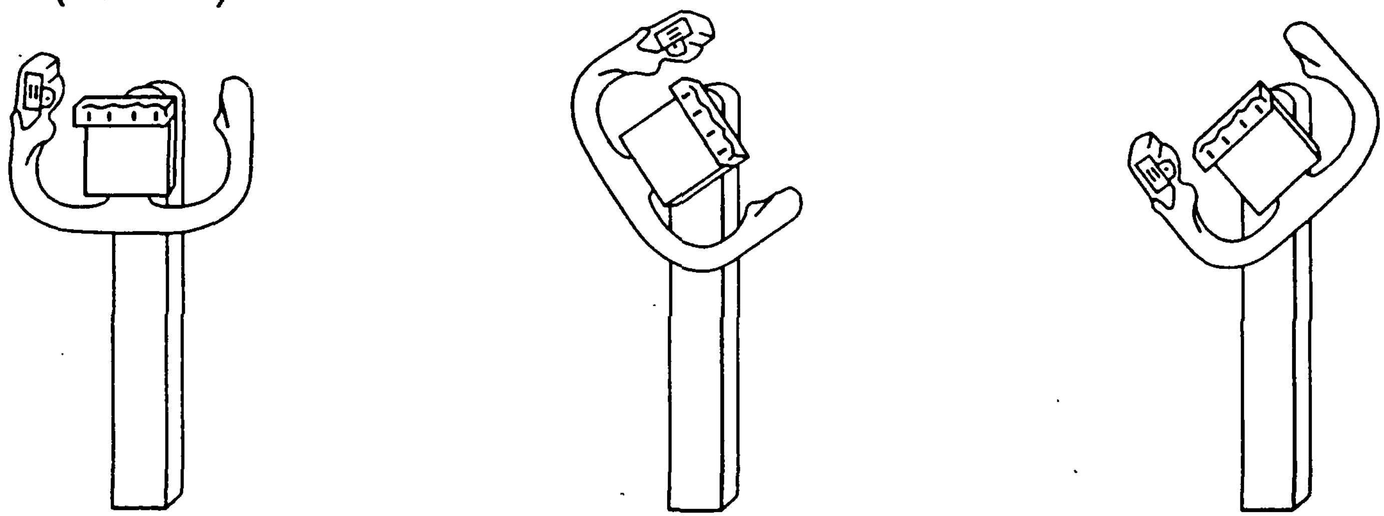
Position information of the flight controls: Wheel, column, and pedals was transformed into a measure of control activity labelled control input activity. The algorithm for reducing the control position information to control inputs uses a "counter" which increments if the difference between consecutive control positions is greater than 2.5% of the total range of travel for that particular control. Since the measurement windows cover different lengths of time the control activity is divided by units of time to yield control input activity per minute.

There was a problem in losing control input data in the low workload condition. If the pilot placed the plane on autopilot, the data for control position, and consequently control input, was not collected. There are measurement windows in the low workload condition which do not contain much data, making the comparison of low and high workload conditions meaningless from a statistical point of view. Yet, with the missing data there is still a strong indication that control input activity can discriminate low and high workload conditions.

Figure 7.1.2.2-6

CONTROL INPUT ACTIVITY

WHEEL (AILERON)
COLUMN (ELEVATOR)
PEDAL (RUDDER)



INCREMENT COUNTER IF 2.5% OF TOTAL RANGE IS EXCEEDED FROM ONE UPDATE TO THE NEXT UPDATE (10 Hz)

COUNTER / MEASUREMENT DURATION = CONTROL ACTIVITY PER MINUTE

CA2068.13

SECONDARY TASK

A secondary task was also implemented to measure pilot spare capacity (spare capacity is thought to be correlated with workload).

Two measures were derived from the Secondary Task: response time to the positive probe and probe accuracy (percentage of positive probes responded to correctly). A constraint was imposed on the time available for subjects to respond. Responses which took longer than 10 seconds were disregarded because the task was not executed immediately.

SECONDARY TASK RESPONSE TIME

ATC would start a timer at the beginning of their utterance when they issued calls to aircraft designated as positive probes. The positive probes were the pilot's own aircraft (For example, "American 247 contact departure control ..."), and another company aircraft in the area (For example, "American 241 descend and maintain ..."). Pilots were instructed to press the push-to-talk (PTT) switch in the left side of the yoke when they heard a positive probe aircraft called by ATC. The PTT switch stopped the timer ATC had activated. The pilot was allowed to write down the call signs of both positive probe aircraft, and had the call signs available to them throughout the flight. All other ATC initiated calls to aircraft were designated as negative probes.

There were two sets of call signs for the positive probes (241 and 247 & 352 and 356). The call signs were counter-balanced across workload condition (low and high) and route (San Francisco-Stockton and Sacramento-San Francisco).

SECONDARY TASK PROBE ACCURACY

Probe accuracy is the percentage of probes correctly responded to per measurement window. Again, the flaws in the positive probing by ATC allows only for a description of trends in the data.

7.1.3 PROCEDURE AND EQUIPMENT

SIMULATOR

The Man-Vehicle System Research Facility (MVSRF) B-727 six degree of freedom motion base simulator was used to provide Phase II certified fidelity. The MVSRF has a number of assets, most notably is the ability to simulate the Air Traffic Control (ATC) environment. The ATC simulation creates realistic levels of communications workload, a part of the standard commercial transport environment often overlooked in simulation.

SCENARIO

There were two routes flown each session. The routes were Sacramento - to - San Francisco (SMF-SFO) and San Francisco - to - Stockton (SFO-SCK). Both flights were flown at 11,000 feet enroute, to ILS approaches and landings.

COUNTER-BALANCE OF CONDITIONS

The presentation of routes is partially counter-balanced across pilots with low and high workload flights. For half of the subjects the SMF-SFO and SFO-SCK are the low and high workload flights, respectively. For the other half of the subjects the combination of flights and workload is reversed, SMF-SFO and SFO-SCK are the high and low workload flights, respectively.

Pilots flew two scenarios, a high and a low workload flight, on both visits. Pilots were randomly assigned to either: 1) SFO-SCK (high workload) and SMF-SFO (low workload), or 2) SFO-SCK (low workload) and SMF-SFO (high workload). Half the subjects flew the high workload scenario first, the other half of the subjects flew the low workload condition first. On the retest day pilots flew the exact same scenario, departure-arrival destinations and workload condition, as the previous session but the scenario order was reversed.

DAILY SCHEDULE

Subject pilots arrived at the MVSRF facility at 9:00 am. Subjects were greeted by the experimenter and tape recorded instructions regarding the day's activities were played for them. Subjects then received "differences training" from Preston Sult (Boeing Flight Crew Training). The differences training involved a discussion of the configuration of the cockpit. The differences training was facilitated by using full-size color photographs of the instrument panels in the simulator. After differences training was completed the pilot was briefed on the routes and weight & balance of the aircraft for the simulation runs.

Following the differences training, tape recorded instructions for the SWAT card sort was played for the pilot. The experimenter provided further clarification on the technique used for the SWAT card sort. The card sort required 20 to 60 minutes to complete.

The pilot and experimenter then went to lunch.

Following lunch the pilot was instrumented with the physiological equipment and placed in the simulator cab. The pilot then departed San Francisco International Airport on runway 28R and spent time flying the aircraft "around the pattern." The pilot was encouraged to practice steep turns, pull the throttle back on an engine, and generally get comfortable with the handling qualities of the simulator. The pilot flew an ILS approach to a touch and go on 28R at SFO. The pilot again flew "around the pattern" to another ILS approach and landing on 28R at SFO.

The pilot then flew the two test trials. Following the test runs the instrumentation was removed from the pilot. Tape recorded instructions on event rating for either SWAT or the NASA-TLX was then played for the pilot. Then the videotape of the simulation test runs was played for the pilot in order to obtain subjective event ratings. Only a small segment (30 seconds) prior to the actual measurement window, and the window itself was played for the purpose of making the event ratings.

Finally, the subject pilot was thanked for participating.

7.1.4 STATISTICAL ANALYSES

Even though there are numerous statistical comparisons made, each workload assessment technique is treated as though it was the only dependent variable utilized in the study. No adjustment was made to the alpha level (probability of a Type I error) for the various comparisons reported from the simulation effort. This approach, referred to by Kirk (1982) as a "contrast-wise Type I error rate" may seem to be liberal. The reason for the contrast-wise Type I error rate is that the statistical effects tested were predicted a priori, and a stringent Type I error rate is applied throughout. A nominal alpha level of 0.01 was adopted for determining significance for all the analyses. Alpha levels between

0.01 and 0.05 were considered as strong trends while alpha levels between 0.05 and 0.10 were considered trends.

Boeing's TLA was utilized to confirm that the manipulations of the pilot's task demands would, in fact, yield a change in the pilot's workload between the "low" and "high" workload flights.

It is necessary to establish a decision rule to be able to determine if a given workload measure has shown validity and reliability. The threshold of the decision rule will most likely generate an argument as to the appropriateness of the threshold, but the rule is necessary for a discussion of the "goodness" (validity and reliability) of the measure.

7.1.4.1 VALIDITY ANALYSES

In order claim validity for any of the assessment techniques it was necessary for the workload measure to discriminate between the low and high workload conditions. A 2 X 2 X 7 repeated measures ANOVA was performed for each workload measure. The factors of the 2 X 2 X 7 ANOVA were session (1 or 2), workload level (low or high), and phase of flight (seven measurement windows), respectively. The means represented in the graphs are from the 2 X 2 X 7 ANOVAs.

An unfortunate artifact of the repeated measures ANOVA approach is the case-wise deletion of subjects owing to missing data in any of the measurement windows. If a subject fails to have data in any of the 28 measurement windows (2 sessions containing 2 flights with 7 measurement windows per flight) for a given workload measure then the entire subject is deleted from the analysis.

All significant $\underline{F}$ ratios are reported, and the results of the test for a main effect of workload will be reported whether there is a statistically significant finding or not.

An a priori prediction is that workload would vary across the phases of flight, for either the low or high workload flight. Although a workload measure may not be able to discriminate among the periods of high workload in a flight (i.e., takeoff, approach, and landing), a workload measure should be able to discriminate low from high within a flight (cruise and landing). Oneway ANOVAs were computed, for both the low and high workload flights, for each workload assessment technique to determine if the various phases of flight could be discriminated from one another.

A simple approach will be taken in examining the discriminability of phase of flight by a workload measure. Utilizing a paired-comparison approach the various phases of flight were compared to one another using the Newman-Kuels range statistic.

7.1.4.2 VALIDITY DECISION CRITERIA

In order for a workload measure to demonstrate validity the measure should find a main effect (discriminate) for the workload factor. Since there is an a priori prediction for a difference in workload for the phases of flight, and the malfunctions in the high workload condition will effect the low workload windows in that flight, an interaction of workload and phase of flight should be present as well. When the malfunctions occur the workload should be significantly higher than the corresponding windows in the low workload condition. A significant workload by window interaction demonstrates that not all windows are significantly different between the low and high workload conditions. A main effect of workload along with a workload by phase of flight interaction indicates appropriate sensitivity of the assessment technique to the manipulation of levels of workload.

An interaction of test session (day 1 or 2) with another factor (e.g., workload or phase of flight) could indicate a number of influences including:

(a) instability of the measure,
(b) practice effect,
(c) adaptation to test conditions.

No systematic attempt was made to describe the nature of the Newman-Kuels range statistic due to complications arising from the large number of comparisons. Our approach, simply stated, is the more significant differences that were found the more discriminable the workload measure was thought to be. (A note to the reader: Even the results for the various body channels of the TLA disassociate, leaving no clear answer in terms of a prediction for global workload differences between the different phases of flight. Therefore a detailed interpretation of phase of flight differences for the various workload measures is beyond the scope of this project.)

7.1.4.3 RELIABILITY ANALYSES

A test/retest methodology was employed so that the reliability of the various measures could be assessed.

In order to compute the correlation coefficients, each measurement window was examined individually. The result of the test/retest evaluation yields 14 different correlation coefficients for the 7 different measurement windows for the 2 different, low and high workload, flights. For each workload measure, the correlations were computed by pairing the session 1 and 2 scores for all the pilots. This approach allows us to examine the reliability of a workload measure under the conditions for a specific phase of flight.

An alternative method for evaluating test/retest reliability would be to examine the session 1 to session 2 pairings of workload scores for the 14 different windows separately for each subject. This method was not chosen because the result only describes the reliability of a workload measure for different subjects. It is already known that some subjects are capable of more reliable assessments than are other subjects. The method employed in the current study, for computing the test/retest correlation coefficient, allows for the examination of the reliability of a measure for certain test conditions (task demands inherent in a given phase of flight) across a variety of subjects.

Unlike the artifact of case-wise deletion found for the repeated measures ANOVAs, the correlation coefficients were computed on as many complete pairs of scores as were available. The principle justification for the unequal samples contributing to the various correlation coefficients is the idea of having as many scores as possible contribute to each correlation. The idea of central tendency dictates that all the scores available from the sample should be used, when possible, to provide a more reliable, or stable, estimate of the population.

Additionally, for each workload measure an estimation of inter-rater reliability was derived by correlating each pilot's score for the 14 measurement windows (average of session 1 and 2) with the group average for the corresponding windows. Inter-rater reliability is then expressed as a percentage of the pilots that show a significant correlation with the group means for the 14 measurement windows.

7.1.4.4 RELIABILITY DECISION CRITERIA

To demonstrate reliability a workload measure should find significant test/retest correlations for the various phases of flight. Unfortunately there is variation in the sample size for the different workload measures. There are sample sizes of 9, 16, and 17 for the subjective, physiological, and performance measures, respectively. The different sample sizes influences the critical Pearson coefficient necessary for a significant correlation. It is therefore very difficult to establish a uniform decision criteria regarding the "goodness" of workload measures' reliability. A good rule of thumb is that each workload measure demonstrate positive correlations that are large (nearer to +1.0 than 0).

For confidence about the inter-rater reliability criteria was established that at least half of the pilots scores (average test/retest) for the 14 measurement windows should be significantly correlated with the group means.

7.2 RESULTS

7.2.1 TIMELINE ANALYSIS RESULTS

To compute the percentage of time required, the total time used by a particular channel (visual, manual, auditory, verbal or cognitive) for the measurement period was divided by time available.

There was no change in procedures during the takeoff window between the high and low workload segments in the scenarios built for TLA. Therefore, for all channels, visual, manual, verbal, auditory and cognitive, the data shown for the takeoff window is identical for high and low workload.

The data on the visual channel (Table 7.2.1-1) shows that visual demands are higher in the high workload scenarios starting at the climb window, when the pilot attempts to engage the autopilot. The higher demand on the visual channel continues through the top of climb when the engine failure occurred, and cruise when the hydraulic failure occurred. The visual demands remain higher through descent, approach, and landing as the pilot is manually flying the aircraft in low visibility for a 15 degree flap landing.

Manual data is computed in TLA for the left hand, right hand, and total manual data (sum of the two hands). The assumption was made in preparing this data that there are continuous corrections (about once per second) made with the left hand in the high workload scenarios, except in the cruise phases when the aircraft is trimmed, then the correction rate becomes once every 5 seconds. These corrections do not occur in the low workload scenarios when the autopilot is engaged. The differences in workload between high and low scenarios in the manual channel (Table 7.2.1-1) occurs starting at the top of climb with the engine failure. In the high workload scenarios the pilot must take actions: the engine failure/shutdown checklists are read, rudder is trimmed, and thrust is adjusted. In cruise, in the low workload scenario, when the autopilot is engaged there is a very low manual requirement. In the high workload scenario in cruise, however, the right hand must take actions as a result of the "B" system hydraulics failure. Descent, approach and landing show a much higher manual requirement in the high workload scenario as might be expected. The pilot is manually flying the aircraft and must respond to checklists required with the failure conditions. The manual sum requirement is over 100% in approach and landing. The pilot is using both right and left hands at the same time and manual sum reflects this.

The verbal component (Table 7.2.1-1) in these flights was low for the pilot. All

Table 7.2.1-1

Timeline Analysis

LOW WORKLOAD						
WINDOW	VISUAL	MANUAL LEFT	MANUAL RIGHT	VERBAL	AUDITORY	COGNITIVE
TAKEOFF	88	65.5	20	5	16	73
CLIMB	97	58.5	28.5	10	51.5	100
TOC	61.5	0	14	2	11	38.5
CRUISE	30	0	1	0	1.5	32
TOD	60	2.5	14	12.5	34	57.5
APPROACH	65.5	3	15.5	5	19	36.5
LANDING	86	61	38	2	14.5	41.5

HIGH WORKLOAD						
WINDOW	VISUAL	MANUAL LEFT	MANUAL RIGHT	VERBAL	AUDITORY	COGNITIVE
TAKEOFF	88	65.5	20	5	16	73
CLIMB	100	58.5	26.5	13	54.5	100
TOC	78.5	13	70.5	14.5	38.5	97.5
CRUISE	37	11	2	10.5	13	37.5
TOD	62	59.5	18	12.5	28.5	60.5
APPROACH	72	57.5	16.5	5	17.5	47.5
LANDING	100	61	56.5	2.5	18.5	50

Percentage of Body Channel Utilized

communications with ATC and dispatch were handled by the first officer. Pilot verbal communications were limited to crew coordination type communications. A small difference occurred in climb because the autopilot did not engage in the high workload scenarios. At the top of climb the pilot makes the decision to shut down the engine and asks the first officer to advise ATC of the failure. In cruise the increase in verbal workload occurs when the hydraulics failure checklist is called for. Though the percent of communication in the high and low workload scenarios in descent and approach is the same, the content is not. In the high workload scenario the pilot is handing off more tasks as he manually flies the aircraft.

For the auditory channei the significant changes between the low and high workload flights occur at the top of climb and in the cruise windows when the checklists are called for after the malfunctions occur. In descent and approach we see a slight reversal due to the pilot taking more of a command role, as discussed in the verbal data.

The cognitive channel is influenced by the number of indicators looked at by the pilot, and the complexity both of the indicators and the procedures performed. In other words, how long it takes the pilot to act is based on the number of choices available. In takeoff and climb the cognitive workload is the same for the high and low scenarios (Table 7.2.1-1). In climb the cognitive channel is at 100% due to reconfiguration tasks, thrust management, heading changes, and completion of the required check lists. In addition, in the high workload scenario, the autopilot fails to engage. At the top of climb (high workload) the cognitive channel is high because of the engine failure. In the high workload flight during cruise the hydraulics failure occurs, and the pilot calls for the appropriate checklist. In descent, approach, and landing there is a higher cognitive load in the high workload scenarios as a result of manually flying the aircraft with an increase in system monitoring and more frequent instrument scanning.

The two low workload scenarios were averaged to yield the low workload scores for the various body channels. Similarly, the two high workload scenarios were averaged to yield the high workload scores for the various body channels (Table 7.2.1-1). Using percentages negates the fact that each of the measurement periods in the simulation was of varying length (ranging from one minute to over 6 minutes).

7.2.2 SUMMARY OF RESULTS

The task analysis provides a link between the past certification workload assessment methods and the workload assessment methods tested in the Part-Task simulation. The comparison of workload assessment methods provides the opportunity to assess the validity of the "pilot in the loop" methods against an analytic tool, namely TLA. If a new workload measure agrees with the task analyses, both probably reflect the same conditions (same task-demands). If the timeline analysis and the workload measure do not agree, but the measure is shown to demonstrate validity and reliability, then the measure may reflect a type of workload not accurately quantified by older techniques.

SWAT, NASA-TLX, the 1-to-20 point Overall Workload Score, and Heart Rate all demonstrated evidence of validity by discriminating workload, and a significant interaction of workload and phase of flight.

NASA-TLX, the 1-to-20 point Overall Workload Score, Eyeblink, and Heart Rate all demonstrated evidence of reliability by finding significant test/retest correlations. In addition, at least 50% of the pilots scores correlated significantly with the group mean for the workload measure.

7.2.2.1 SUBJECTIVE RATINGS

SWAT, NASA-TLX, and the 1-to-20 point overall workload score demonstrated evidence for validity by discriminating between low and high workload. In addition, the NASA-TLX and the 1-to-20 point Overall Workload Score demonstrated evidence of being reliable measures.

SWAT

To yield the appropriate 0 to 100 scaling solution for the SWAT ratings, the group scaling solution was used for the SWAT card sort. The Kendall's coefficient of concordance comparing the ranks of the card sorts for the various pilots was greater (0.7824) than the recommended 0.78 for using the group scaling solution.

SWAT discriminated between the low and high workload flights, $F(1,8)=17.20$, ($MSe=1313$, $p<.01$) (Figure 7.2.2.1-1 and Table 7.2.2.1-1). A workload by phase of flight interaction was significant as well, $F(6,48)=9.58$, ($MSe=156$, $p<.01$).

A strong trend for a main effect for phase of flight discrimination was found, $F(6,48)=2.93$, ($MSe=298$, $p<.02$). No main effect was found for a oneway ANOVA examining phase of flight discrimination for the low workload flight, $F(6,48)=1.55$, ns. A significant main effect was found for a oneway ANOVA examining phase of flight discrimination in the high workload condition, $F(6,48)=7.55$, ($MSe=139$, $p<.01$). A Newman-Kuels range statistic was computed to determine SWAT's ability to discriminate phase of flight for the high workload flight 5 out of 21 comparisons were significant.

In evaluating the test/retest reliability of SWAT 2 significant correlations, out a possible 14, were found (Table 7.2.2.1-2).

Examining inter-rater reliability found 78% of the subject's scores correlated significantly with the means for the 14 measurement windows.

NASA-TLX

To yield the appropriate 0 to 100 workload scaling solution for the NASA-TLX, each individual's weighting scores were applied to their event ratings.

NASA-TLX discriminated between the low and high workload flights, $F(1,7)=17.27$, ($MSe=436$, $p<.01$) (Figure 7.2.2.1-2 and Table 7.2.2.1-3). A workload by phase of flight interaction was significant as well, $F(6,42)=4.69$, ($MSe=126$, $p<.01$).

A main effect for phase of flight discrimination was found, $F(6,42)=4.19$, ($MSe=84$, $p<.01$). No main effect was found for a oneway ANOVA examining phase of flight discrimination for the low workload flight, $F(6,42)=1.75$, ns. A significant main effect was found for a oneway ANOVA examining phase of flight discrimination for the high workload flight, $F(6,48)=7.14$, ($MSe=68$, $p<.01$). A Newman-Kuels range statistic was computed to determine NASA-TLX's ability to discriminate phase of flight conditions for the high workload flight 5 out of 21 comparisons were significant.

In evaluating the test/retest reliability of NASA-TLX 4 significant correlations, out of a possible 14, were found (Table 7.2.2.1-4).

Examining inter-rater reliability found 78% of the subject's scores correlated significantly with the means for the 14 measurement windows.

Figure 7.2.2.1-1

Subjective Workload Assessment Technique (SWAT)

Part Task Simulation Mean Scores

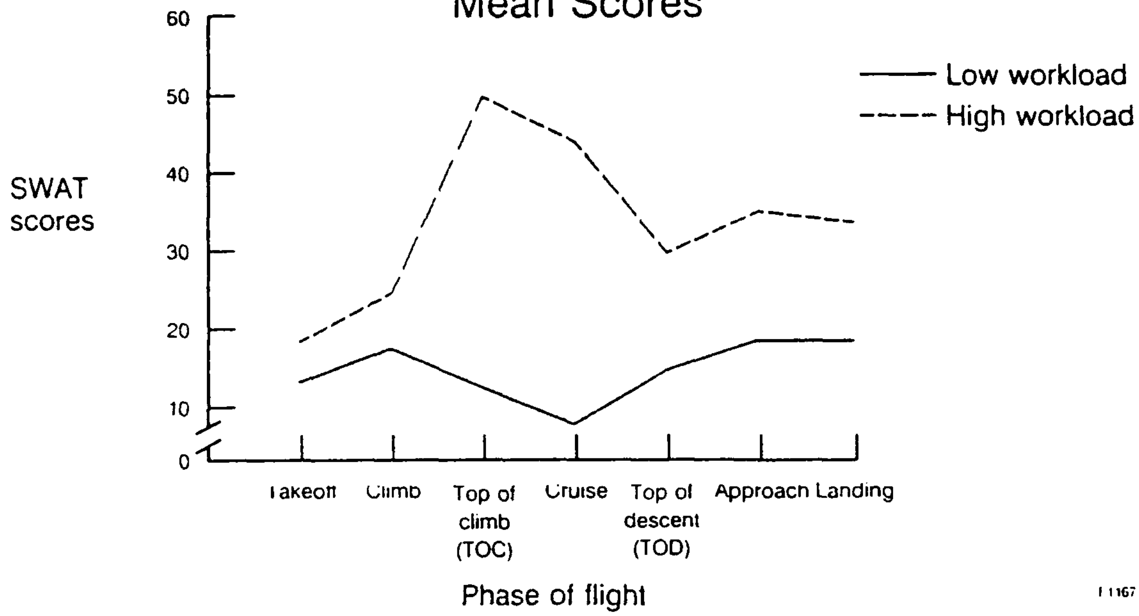


Table 7.2.2.1-1

Subjective Workload Assessment Technique (SWAT)

Part Task Simulation Data Means and Standard Deviations

Window	Low-workload flight Mean	Low-workload flight SD	High-workload flight Mean	High-workload flight SD
Takeoff	13.21	(14.77)	18.41	(16.64)
Climb	17.52	(17.53)	24.59	(19.04)
Top of climb	12.51	(10.67)	49.77	(24.54)
Cruise	7.83	(13.69)	44.04	(22.28)
Top of descent	14.67	(9.47)	29.74	(18.04)
Approach	18.46	(11.56)	34.97	(19.05)
Landing	18.53	(10.84)	33.72	(20.94)

Table 7.2.2.1-2

SWAT

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	0.46	0.83*
Climb	0.44	0.70
Top of climb	-0.01	0.80*
Cruise	0.67	0.46
Top of descent	-0.18	0.41
Approach	0.10	0.69
Landing	-0.0005	0.48

r(7) = .798*
*Significant p<.01

F 1167 76 H5rs

Figure 7.2.2.1-2

NASA Task Load Index (TLX)

Part Task Simulation

Mean Scores

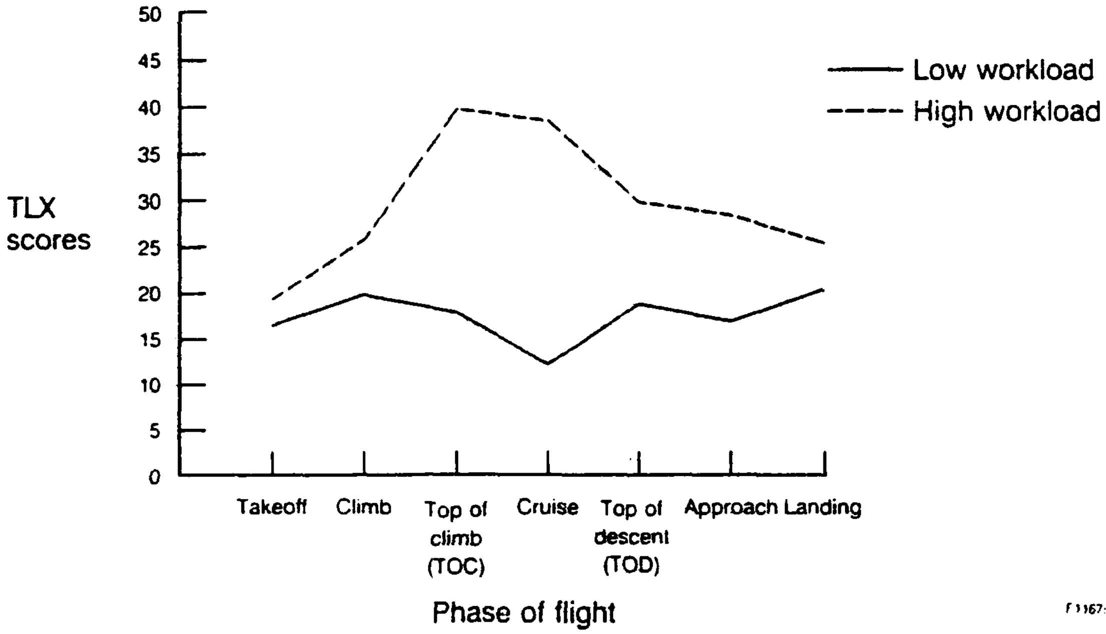


Table 7.2.2.1-3

NASA - Task Load Index (TLX)

Part Task Simulation Data

Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	16.50	(7.75)	19.28	(8.69)
Climb	19.81	(11.63)	25.78	(10.62)
Top of climb	17.88	(9.87)	39.78	(16.78)
Cruise	12.19	(4.14)	38.50	(20.57)
Top of descent	18.75	(10.55)	29.78	(12.41)
Approach	16.94	(9.05)	28.39	(10.96)
Landing	20.25	(12.22)	25.39	(13.10)

Table 7.2.2.1-4

NASA-TLX

Part Task Simulation
Test-Retest
Reliability Correlations

Window	Low	High
Takeoff	0.79	0.61
Climb	0.41	0.57
Top of climb	0.21	0.56
Cruise	0.47	0.82*
Top of descent	0.87*	0.51
Approach	0.94*	0.47
Landing	0.61	0.83*

$r(7) = 0.798$*
*Significant $p < 0.01$

F1167.77 R7G

1-to-20 POINT OVERALL WORKLOAD SCORE

The 1-to-20 point workload score was analyzed without any sort of transformation of the event ratings.

The 1-to-20 overall workload score discriminated between the low and high workload flights $F(1,8)=27.14$, ($MSe=16$, $p<.01$) (Figure 7.2.2.1-3 and Table 7.2.2.1-5). A workload by phase of flight interaction was significant as well, $F(6,48)=7.41$, ($MSe=5$, $p<.01$).

A main effect was found for phase of flight discrimination was found, $F(6,48)=4.15$, ($MSe=4.8$, $p<.01$). No main effect was found for a oneway ANOVA examining phase of flight discrimination for the low workload flight, $F(6,48)=2.35$, ns. A significant main effect was found for the oneway ANOVA examining phase of flight discrimination for the high workload flight, $F(6,48)=8.22$, ($MSe=3$, $p<.01$). A Newman-Kuels range statistic was computed to determine NASA-TLX's ability to discriminate phase of flight for the high workload flight 5 out of 21 comparisons were significant.

In evaluating the test/retest reliability of the overall workload score 4 significant correlations, out of a possible 14, were found (Table 7.2.2.1-6).

Examining inter-rater reliability found 78% of the subject's scores correlated significantly with the means for the 14 measurement windows.

7.2.2.2 PHYSIOLOGICAL MEASURES

Heart rate, as measured by inter-beat interval and the respiration component of the Power Spectral analysis both demonstrated evidence for validity by discriminating between low and high workload. In addition, eyeblink rate and inter-beat interval both demonstrated evidence of reliability.

EYEBLINKS

Eyeblink rate was not able to discriminate low and high workload conditions, $F < 1$ (Figure 7.2.2.2-1 and Table 7.2.2.2-1). A session by workload by phase of flight interaction was significant, $F(6,84)=3.52$, ($MSe=111$, $p<.01$) indicating instability of the measure over time as well as some sort of habituation of the eyeblink response.

A main effect for phase of flight discrimination was found, $F(6,84)=35.35$, ($MSe=345$, $p<.01$). Two separate oneway ANOVAs were performed and significant main effects for phase of flight were found for both the low and high workload flights, $F(6,96)=7.14$, ($MSe=20$, $p<.01$) and $F(6,96)=10.61$, ($MSe=23$, $p<.01$), respectively. Eyeblink rate could discriminate 3 out of 21, and 6 out of 21, phase of flight comparisons for the low and high workload conditions, respectively.

The eyeblink data demonstrated good test-retest reliability, 8 out of a possible 14 correlations were significant (Table 7.2.2.2-2).

Examining inter-rater reliability found 56% of the subjects correlated significantly with the means per measurement window).

Figure 7.2.2.1-3

Overall Workload Score 1- to 20-Point

Part Task Simulation
Mean Scores

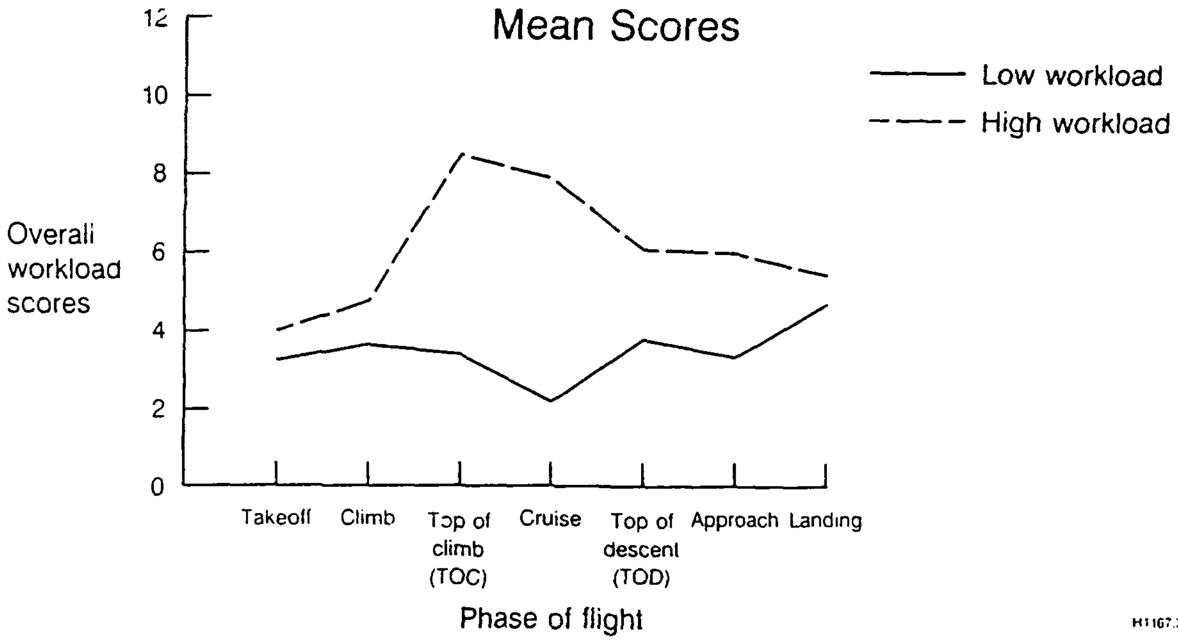


Table 7.2.2.1-5

1-20 Point Overall Workload Score

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	3.22	(2.06)	3.94	(2.19)
Climb	3.61	(2.18)	4.78	(2.02)
Top of climb	3.39	(2.10)	8.50	(3.22)
Cruise	2.22	(0.97)	7.94	(4.28)
Top of descent	3.78	(2.56)	6.11	(2.62)
Approach	3.39	(2.13)	6.00	(2.82)
Landing	4.67	(3.32)	5.50	(3.06)

H1167.17 R3ab

Table 7.2.2.1-6

1- to 20-Point Overall Workload

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	0.77	0.80*
Climb	0.12	0.37
Top of climb	0.28	0.66
Cruise	0.45	0.75
Top of descent	0.97*	0.51
Approach	0.93*	0.46
Landing	0.83*	0.76

r(7) = .798*
*Significant p< .01

Figure 7.2.2.2-1

Eyeblink Rate (Blinks per Minute)

Part Task Simulation
Mean Scores

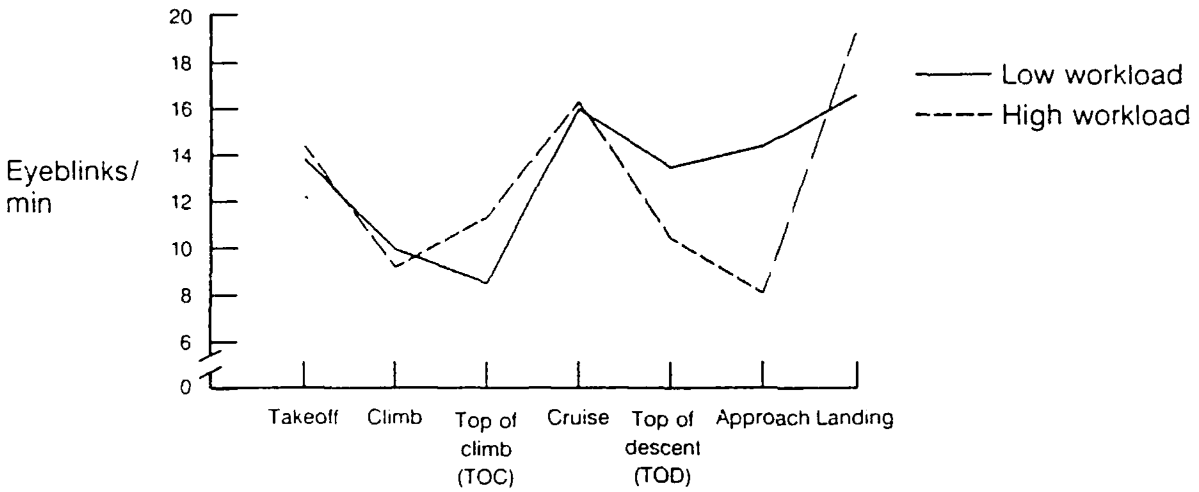


Table 7.2.2.2-1

Eyeblink Rate (Blinks per Minute)

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	14.32	(5.80)	13.65	(6.50)
Climb	10.18	(5.97)	9.26	(6.05)
Top of climb	8.29	(5.54)	11.32	(9.30)
Cruise	14.44	(6.19)	13.53	(8.08)
Top of descent	10.53	(6.60)	9.00	(4.85)
Approach	12.09	(5.75)	7.97	(6.32)
Landing	16.41	(6.20)	18.94	(8.43)

Table 7.2.2.2-2

Eyeblink Rate (Blinks per Minute)

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	0.6	0.7*
Climb	0.34	0.63*
Top of climb	0.84*	0.84*
Cruise	0.31	0.75*
Top of descent	0.67*	0.58
Approach	0.59	0.74*
Landing	0.41	0.74*

$r(15) = .606$*
*Significant $p < .01$

F 110? 71 85/s

HEART RATE (INTER-BEAT INTERVAL)

Interbeat interval discriminated between the low and high workload flights, $F(1,16)=27.74$, ($MSe=2763$, $p<.01$) (Figure 7.2.2.2-2 and Table 7.2.2.2-3). A workload by phase of flight interaction was significant as well, $F(6,96)=5.69$, ($MSe=446$, $p<.01$).

There is a strong trend for a main effect of session, day 1 has smaller IBIs than day 2, $F(1,16)=7.81$, ($MSe=34357$, $p<.02$). This effect indicates that the pilots do not experience as much workload on the second session. As was mentioned for the same interaction found for eyeblink, there may be instability of the measure over time. A more likely explanation for the interaction is that there is adaptation occurring because the pilot is experiencing identical conditions during the retest.

A significant main effect for phase of flight discrimination was found, $F(6,96)=23.32$, ($MSe=1279$, $p<.01$). Separate oneway ANOVAs were performed and significant main effects were found for phase of flight discrimination for both the low and high workload flights, $F(6,102)=22.61$, ($MSe=397$, $p<.01$) and $F(6,90)=15.04$, ($MSe=454$, $p<.01$), respectively. Inter-beat interval could discriminate 14 out of 21, and 9 out of 21, phase of flight comparisons for the low and high workload conditions, respectively.

In evaluating test-retest reliability for inter-beat interval 6, out of a possible 14, correlations were significant (Table 7.2.2.2-4).

Examining inter-rater reliability found 78% of the subjects correlated significantly with the means per measurement window.

HEART RATE VARIABILITY (IBI STANDARD DEVIATION)

Heart rate variability (IBI standard deviation) was not able to discriminate the difference between low and high workload conditions, $F(1,16)=1.75$, ns (Figure 7.2.2.2-3 and Table 7.2.2.2-5).

A significant main effect for phase of flight discrimination was found, $F(6,96)=14.13$, ($MSe=196$, $p<.01$). A oneway ANOVA found no main effect for phase of flight discrimination for the low workload condition, $F(6,102)=2.11$, ns. A significant main effect for phase of flight discrimination was found for the high workload flight, $F(6,90)=11.90$, ($MSe=63$, $p<.01$). Inter-beat interval standard deviation could discriminate 10 out of 21 phase of flight comparisons for the high workload conditions.

Test-retest reliability for inter-beat interval variability was not as high as mean IBI, 5 out of a possible 14, correlations were significant (Table 7.2.2.2-6).

In assessing inter-rater reliability it was found that 44% of the subjects scores were significantly correlated with means for the measurement windows.

POWER SPECTRAL ANALYSIS (BLOOD PRESSURE COMPONENT)

The blood pressure component was not able to discriminate the difference between low and high workload, $F(1,15)=4.75$, ns (Figure 7.2.2.2-4 and Table 7.2.2.2-7).

A main effect for phase of flight discrimination was found, $F(6,90)=8.54$, ($MSe=54$, $p<.01$). Separate oneway ANOVAs were performed and significant main effects were found for phase of flight discrimination for both the low and high workload flights, $F(6,102)=7.26$, ($MSe=23$, $p<.01$) and $F(6,90)=3.59$, ($MSe=23$, $p<.01$), respectively.

Figure 7.2.2.2-2

Inter-Beat Interval (Msec)

Part Task Simulation

Mean Scores

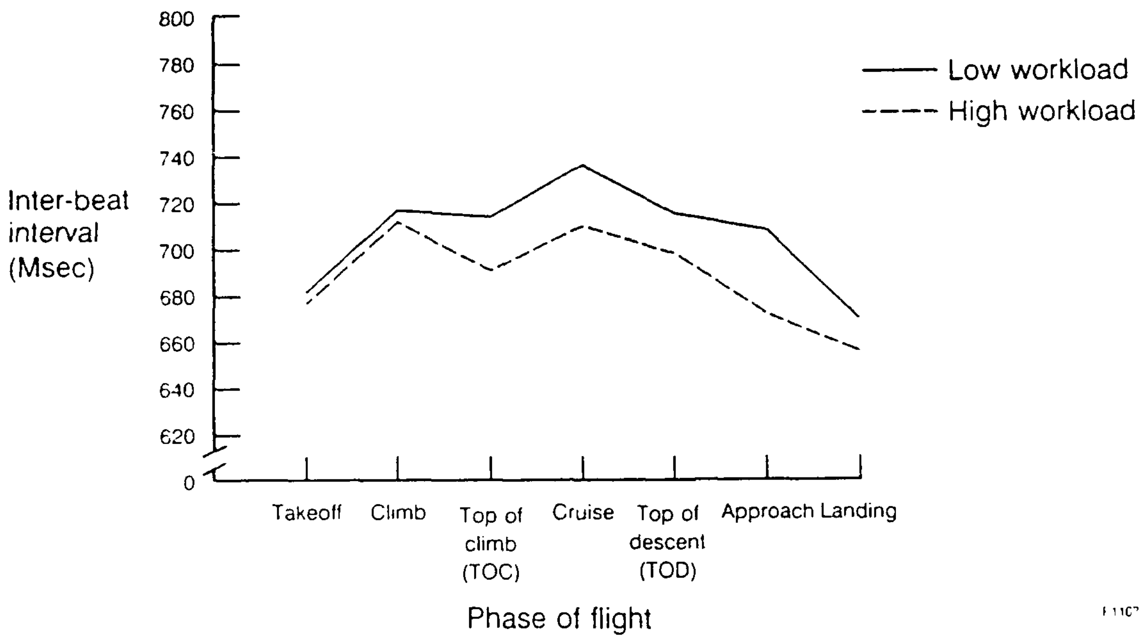


Table 7.2.2.2-3

Inter-Beat Interval (Msec)

Part Task Simulation Data

Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	682	(74.10)	677	(72.04)
Climb	717	(81.65)	712	(75.89)
Top of climb	714	(73.84)	691	(70.92)
Cruise	736	(70.15)	710	(70.42)
Top of descent	715	(78.61)	698	(65.92)
Approach	708	(74.87)	672	(66.63)
Landing	670	(61.58)	656	(58.52)

H11C7 19 R4db

Table 7.2.2.2-4

Inter-Beat Interval (Msec)

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	0.61*	0.68*
Climb	0.61*	0.53
Top of climb	0.66*	0.5
Cruise	0.53	0.45
Top of descent	0.67*	r(15) = 0.53
Approach	0.67*	0.55
Landing	0.5	0.53

r(16) = 0.590*
*Significant $p < 0.01$

F 1167 72 R8G

Figure 7.2.2.2-3

Inter-Beat Interval
Standard Deviation (Msec)

Part Task Simulation
Mean Scores

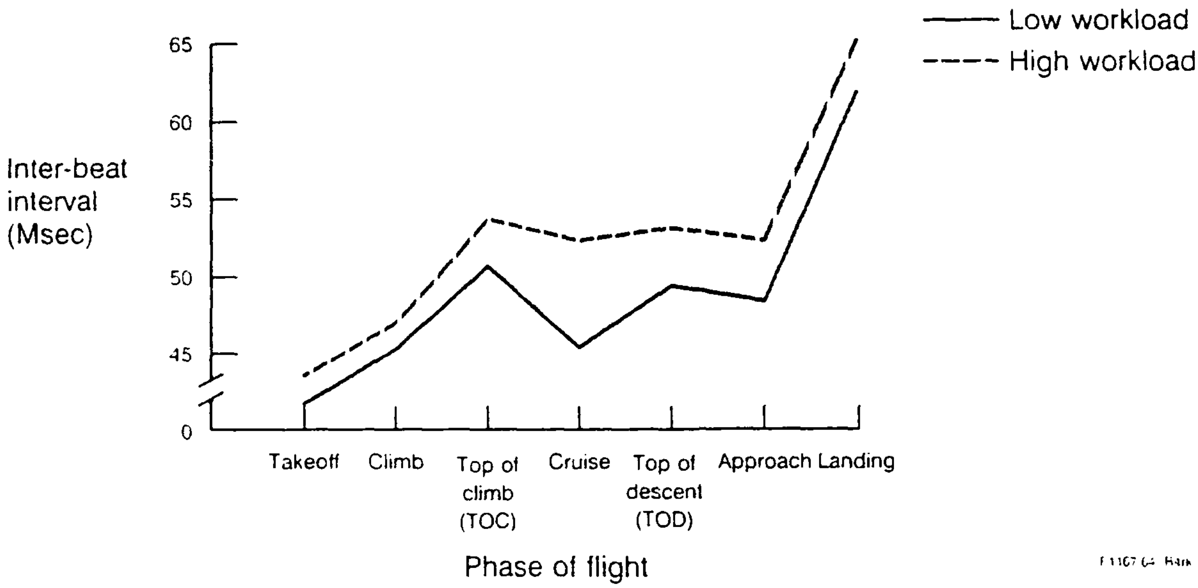


Table 7.2.2.2-5

Inter-Beat Interval
Standard Deviation (Msec)

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	41.58	(17.05)	39.04	(15.09)
Climb	41.55	(13.90)	43.99	(10.28)
Top of climb	47.27	(16.93)	50.08	(12.83)
Cruise	43.80	(9.73)	49.09	(14.26)
Top of descent	47.03	(11.67)	50.20	(12.15)
Approach	57.16	(50.45)	49.02	(15.93)
Landing	58.54	(13.80)	61.33	(12.82)

Table 7.2.2.2-6

Inter-Beat Interval
Standard Deviation (Msec)

Part Task Simulation
Test-Retest
Reliability Correlations

Window	Low	High
Takeoff	0.52	0.7*
Climb	0.39	0.24
Top of climb	0.61*	0.31
Cruise	0.16	0.7*
Top of descent	0.68*	r(15) = 0.48
Approach	0.78*	0.52
Landing	0.25	0.16

r(16) = .590*
*Significant p<.01

F 1167 73 HGrs

Figure 7.2.2.2-4

Power Spectral Analysis (Blood Pressure Component)

Part Task Simulation
Mean Scores

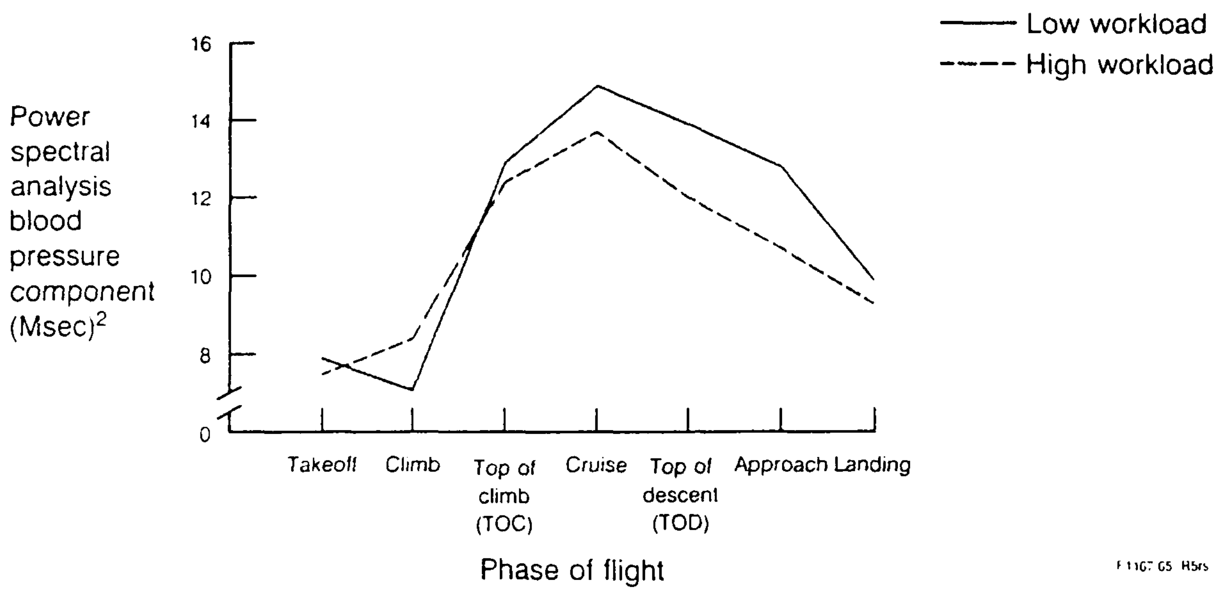


Table 7.2.2.2-7

Power Spectral Analysis (Blood Pressure Component)

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	7.87	(6.83)	7.50	(8.90)
Climb	7.14	(4.72)	8.38	(4.94)
Top of climb	12.92	(9.77)	12.37	(6.63)
Cruise	14.89	(9.21)	13.72	(9.05)
Top of descent	13.91	(8.65)	11.95	(6.61)
Approach	12.84	(8.89)	10.72	(5.82)
Landing	9.93	(7.03)	9.33	(5.08)

H1167 21 H3db

The Blood Pressure component could discriminate 7 out of 21, and 1 out of 21, phase of flight comparisons for the low and high workload conditions, respectively.

The blood pressure component demonstrated poor test/retest reliability, 2 out of 14 possible correlations were significant (Table 7.2.2.2-8).

In assessing inter-rater reliability it was found that 17% of the subjects significantly correlated with the means for the measurement windows.

POWER SPECTRAL ANALYSIS (RESPIRATION COMPONENT)

The respiration component was able to discriminate the low and high workload conditions $F(1,15)=9.17$, ($MSe=10$, $p<.01$) (Figure 7.2.2.2-5 and Table 7.2.2.2-9).

A main effect for phase of flight discrimination was found, $F(6,90)=3.01$, ($MSe=16$, $p<.01$). The respiration component of the power spectral analysis could not discriminate among the phases of flight for the low workload condition, $F(6,102)=2.19$, ns. A significant main effect for phase of flight discrimination was found for the high workload flight, $F(6,90)=3.43$ ($MSe=7$, $p<.01$). Newman-Kuels analyses of the windows found no ability to discriminate the various phases of flight for either the low or high workload conditions.

Evaluating test/retest reliability for the respiration component found 4, out of a possible 14, correlations significant (Table 7.2.2.2-10).

In assessing inter-rater reliability measures it was found 28% of the subjects significantly correlated with the means for the measurement windows.

7.2.2.3 PERFORMANCE MEASURES

Control activity during manual flight path control demonstrated a strong trend for discriminability between low and high levels of workload. Tremendous attrition of control activity data occurred in the low workload condition due to autopilot usage. During auto-flight control activity is not considered a measure of workload because the pilot is no longer in the control loop. Test/retest reliability was high for the control activity measures.

CONTROL INPUT ACTIVITY

WHEEL (AILERON) CONTROL ACTIVITY

For wheel control activity (aileron inputs) there is a strong indication of more control activity for the high workload condition, $F(1,1)=153.2$, ns, (Figure 7.2.2.3-1 and Table 7.2.2.3-1).

A strong trend for a main effect for phase of flight discrimination was found, $F(6,6)=7.83$, ($MSe=68$, $p<.012$). No significant main effect for phase of flight discrimination was found for the low workload flight, $F(6,6)=3.29$, ns. A significant main effect was found for phase of flight discrimination for the high workload flight $F(6,96)=20.45$ ($MSe=41.7$, $p<.01$). Wheel control activity could discriminate 10 out of 21 phase of flight comparisons for the high workload condition.

Test-retest reliability for wheel control activity was very high, 9 significant correlations out of a possible 14 (Table 7.2.2.3-2).

Table 7.2.2.2-8

Power Spectrum Analysis (Blood Pressure Component)

Part Task Simulation
Test-Retest
Reliability Correlations

Window	Low	High
Takeoff	0.29	0.57
Climb	0.54	0.34
Top of climb	0.59	0.11
Cruise	0.31	0.22
Top of descent	0.73*	r(15) = 0.27
Approach	0.24	0.45
Landing	0.5	r(15) = 0.12

r(16) = .590*
*Significant p< .01

I 1167 74 87rs

Figure 7.2.2.2-5

Power Spectral Analysis (Respiration Component)

Part Task Simulation
Mean Scores

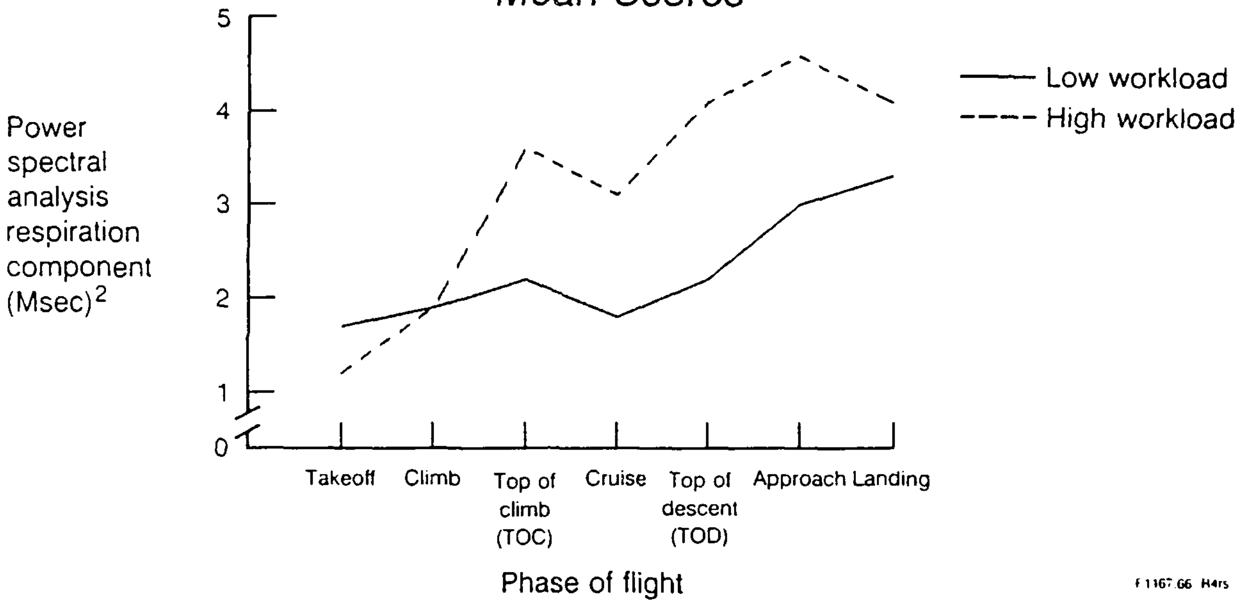


Table 7.2.2.2-9

Power Spectral Analysis (Respiration Component)

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	1.67	(1.71)	1.25	(0.90)
Climb	1.90	(1.80)	1.85	(1.35)
Top of climb	2.15	(1.88)	3.62	(3.07)
Cruise	1.77	(0.99)	3.07	(2.43)
Top of descent	2.16	(1.77)	4.09	(5.22)
Approach	2.95	(4.11)	4.64	(5.87)
Landing	3.26	(2.37)	4.10	(2.84)

H1167.22 R4db

Table 7.2.2.2-10

Power Spectral Power (Respiration Component)

Part Task Simulation
Test-Retest
Reliability Correlations

Window	Low	High
Takeoff	0.17	0.33
Climb	0.33	0.12
Top of climb	0.79*	0.43
Cruise	0.02	0.36
Top of descent	0.58	r(15) = 0.83*
Approach	0.93*	0.79*
Landing	0.52	r(15) = 0.23

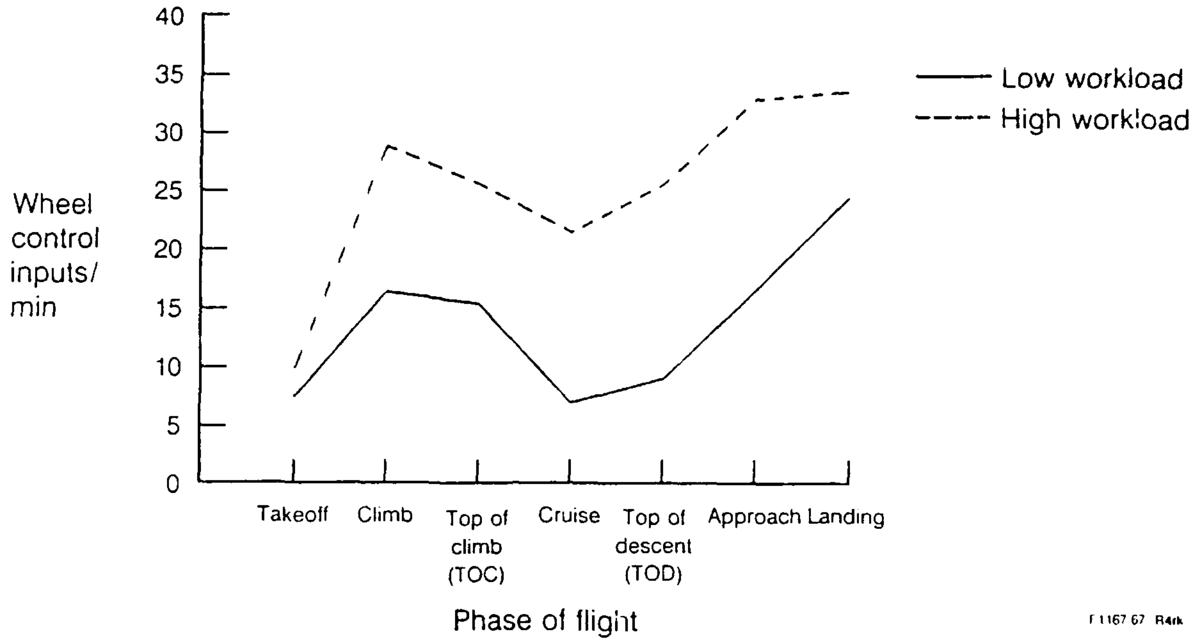
r(16) = .590*
*Significant p< .01

F 1107 75 |87rs

Figure 7.2.2.3-1

Wheel (Aileron) Control Inputs (per Minute)

Part Task Simulation
Mean Scores



F 1167 67 R4rk

Table 7.2.2.3-1

Wheel (Aileron) Control Inputs

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	8.98	(2.23)	9.43	(6.42)
Climb	18.28	(6.73)	21.74	(12.93)
Top of climb	14.26	(3.19)	22.97	(11.60)
Cruise	5.40	(1.13)	19.42	(12.52)
Top of descent	9.95	(1.35)	24.70	(11.06)
Approach	21.12	(11.91)	31.23	(12.09)
Landing	27.64	(16.83)	35.79	(12.98)

H1167 23 R4db

Table 7.2.2.3-2

Wheel (Aileron) Control Inputs

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	r(16) = 0.61	r(16) =0.65*
Climb	r(16) = 0.58	r(16) =0.75*
Top of climb	r(5) =-0.44	r(16) =0.77*
Cruise	---	r(16) =0.88*
Top of descent	r(10) = 0.07	r(15) =0.95*
Approach	r(12) = 0.86*	r(16) =0.70*
Landing	r(16) = 0.60*	r(16) =0.65*

*Significant

F1167 79 RGN

Inter-rater reliability is not available owing to missing data for the low workload conditions in which the autopilot is used.

COLUMN (ELEVATOR) CONTROL ACTIVITY

For column control activity (elevator inputs) there is a strong indication for more control activity for the high workload condition, $F(1,1)=18.06$, ns, (Figure 7.2.2.3-2 and Table 7.2.2.3-3).

A main effect was found for session, $F(1,1)=6782$, ($MSe=0.02$, $p<.01$). The pilots did not make as many inputs to the elevator when flying the scenarios on the second day. This finding probably reflects the fact that the pilots became more familiar with the handling qualities of the motion base simulator over time.

A main effect for phase of flight discrimination was found, $F(6,6)=14.73$, ($MSe=146$, $p<.01$). Separate oneway ANOVAs were performed and significant main effects were found for phase of flight discrimination for both the low and high workload flights, $F(6,6)=24.75$ ($MSe=12$, $p<.01$) and $F(6,96)=16.30$ ($MSe=94$, $p<.01$), respectively. Column control activity could discriminate 6 out of 21, and 9 out of 21, phase of flight comparisons for the low and high workload conditions, respectively.

Test-retest reliability for wheel control activity was very high, 10 significant correlations out of a possible 14 (Table 7.2.2.3-4).

Inter-rater reliability is not available owing to missing data for the low workload conditions in which the autopilot is used.

PEDAL (RUDDER) CONTROL INPUT ACTIVITY

When examining pedal control input activity it should be considered that the rudder pedals are seldom used except during the takeoff and landing phases of flight. The Climb, Top of Climb, Cruise, Top of Descent, and Descent measurement periods average very few rudder inputs, less than zero, per minute.

For pedal control activity (rudder inputs) there is no discernable difference between low and high workload conditions, $F(1,1)=1.01$, ns, (Figure 7.2.2.3-3 and Table 7.2.2.3-5).

A main effect for phase of flight discrimination was found, $F(6,6)=14.73$, ($MSe=146$, $p<.01$). Separate oneway ANOVAs were performed and significant main effects were found for phase of flight discrimination for both the low and high workload flights, $F(6,6)=16.79$ ($MSe=26$, $p<.01$) and $F(6,96)=100.65$ ($MSe=27$, $p<.01$), respectively. Pedal control activity could discriminate 10 out of 21, and 11 out of 21, phase of flight comparisons for the low and high workload conditions, respectively.

Test-retest reliability for pedal control activity was not as high as either wheel or column control activity, 6 significant correlations out of a possible 14 (Table 7.2.2.3-6).

Inter-rater reliability is not available because of missing data for the low workload conditions in which the autopilot is used.

SECONDARY TASK

There were some implementation problems encountered with the secondary task. A post hoc examination of the accuracy of probe delivery indicates that ATC personnel did

Figure 7.2.2.3-2

Column (Elevator) Control Inputs (per Minute)

Part Task Simulation

Mean Scores

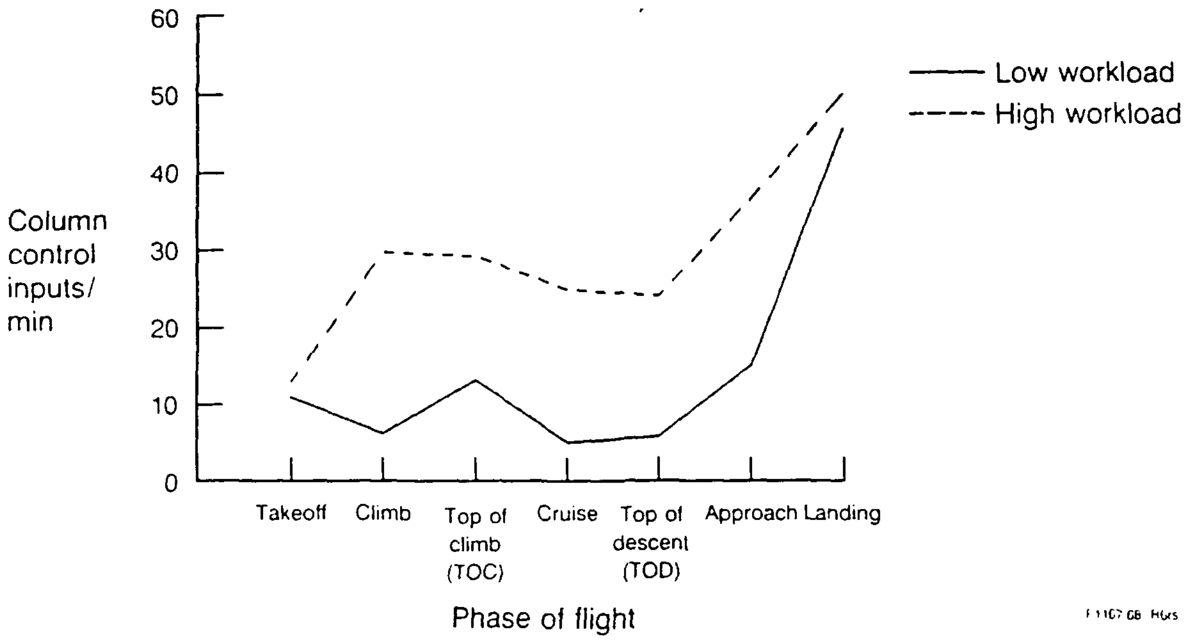


Table 7.2.2.3-3

Column (Elevator) Control Inputs

Part Task Simulation Data

Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	8.85	(7.34)	10.99	(5.07)
Climb	6.76	(3.19)	20.20	(16.67)
Top of climb	9.38	(3.72)	23.66	(16.47)
Cruise	1.50	(0.99)	18.06	(10.55)
Top of descent	4.74	(0.09)	20.02	(16.29)
Approach	13.34	(4.51)	29.77	(17.86)
Landing	38.13	(8.48)	40.61	(12.12)

H1167.24 R3ob

Table 7.2.2.3-4

Column (Elevator) Control Inputs

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	r(16)=0.64*	r(16) =0.81*
Climb	r(16)=0.61*	r(16) =0.78*
Top of climb	r(5) =0.54	r(16) =0.83*
Cruise	---	r(16) =0.54
Top of descent	r(10)=0.20	r(15) =0.89*
Approach	r(12)=0.74*	r(16) =0.77*
Landing	r(16)=0.63*	r(16) =0.73*

*Significant

F1167.60 H7rk

Figure 7.2.2.3-3

Pedal (Rudder) Control Inputs (per Minute)

Part Task Simulation
Mean Scores

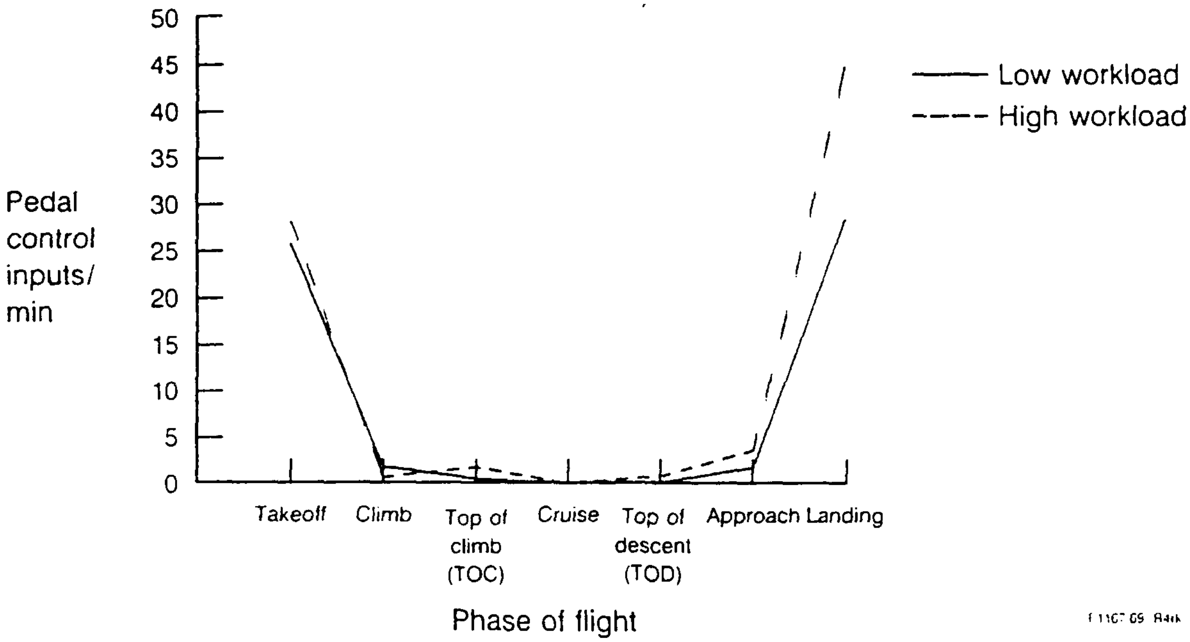


Table 7.2.2.3-5

Pedal (Rudder) Control Inputs

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	33.39	(14.34)	28.11	(13.71)
Climb	3.26	(3.90)	0.71	(0.95)
Top of climb	1.00	(1.06)	1.79	(1.89)
Cruise	0.00	(0.00)	0.11	(0.30)
Top of descent	0.34	(0.48)	0.83	(1.57)
Approach	3.13	(4.42)	3.62	(6.32)
Landing	29.98	(0.23)	44.69	(13.58)

H1167.25 H3db

Table 7.2.2.3-6

Pedal (Rudder) Control Inputs

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	r(16) = 0.61*	r(16) = 0.72*
Climb	r(16) = -0.06	r(16) = 0.78*
Top of climb	r(5) = 0.64	r(16) = 0.21
Cruise	---	r(16) = 0
Top of descent	r(10) = 0	r(15) = 0.88*
Approach	r(12) = 0.99*	r(16) = 0.99*
Landing	r(16) = 0.25	r(16) = 0.53

*Significant

F1167 81 R7%

not deliver the probes in a consistent fashion across the different subjects.

SECONDARY TASK (RESPONSE TIME)

Owing to the case-wise deletion of data with missing cell entries, there were no valid cases left to analyze for testing validity (discriminability of low/high workload or phase of flight). Even with all the flaws in the data collection there was a pattern emerged for faster response times in the low workload condition (Figure 7.2.2.3-4 and Table 7.2.2.3-7).

A statistical analysis of the reliability measures for response time was muddled because of the discrepant sample sizes due to the flawed probe presentation (Table 7.2.2.3-8).

SECONDARY TASK (PROBE ACCURACY)

No clear trends for discriminating low and high workload are found for probe accuracy (Figure 7.2.2.3-5 and Table 7.2.2.3-9). From Top of Climb through landing there is greater probe accuracy for the low workload condition. Again, analyses for phase of flight discriminability was precluded due to missing data among the various windows.

Similar to Response Time, the statistical analysis of reliability for Probe Accuracy was muddled because of the discrepant sample sizes for the different phases of flight (Table 7.2.2.3-10).

7.3 RELATIONSHIP OF WORKLOAD MEASURES

A correlation matrix of all the workload measures was computed with the means for the 14 phases of flight (7 windows from the low and high workload flights). Caution should be exercised in extrapolating any relationship between the workload measures from a correlation matrix constructed in this fashion. The correlation matrix (Tables 7.3-1 and 7.3-2) allows the reader to compare various measures to determine which measures are sensitive to the same changes in task demands.

The correlations (test/retest and inter-rater) presented earlier were constructed in an entirely different fashion. For each workload score, the test/retest correlations were constructed individually for each phase of flight by correlating the session one and two scores for all the pilots. For each workload score, the inter-rater correlations were computed for each pilot by correlating the average of his session one and two scores for all 14 phases of flight to the group averages for the 14 phases of flight.

Included in the correlation matrix are the results from the Boeing TLA. The reader should be aware of the difference between the workload measures collected in the Part-Task simulation and values from the Boeing TLA. The workload measures collected from the pilots represents averages calculated from a distribution of scores based on sample sizes ranging from 9 to 18. The mean for each cell is then used for the various workload measures in the correlation matrix. On the other hand, the Timeline Analysis represents a micro-motion analysis which yields a single value for each body channel for the various phases of flight. It is the single value for TLA body channel which is used along with the means for the various workload measures to compute the correlation matrix.

7.4 PRINCIPAL COMPONENT ANALYSIS

A Principal Component Analysis was computed on the averages for the 14 phases of

Figure 7.2.2.3-4

Secondary Task (Response Time)

Part Task Simulation
Mean Scores

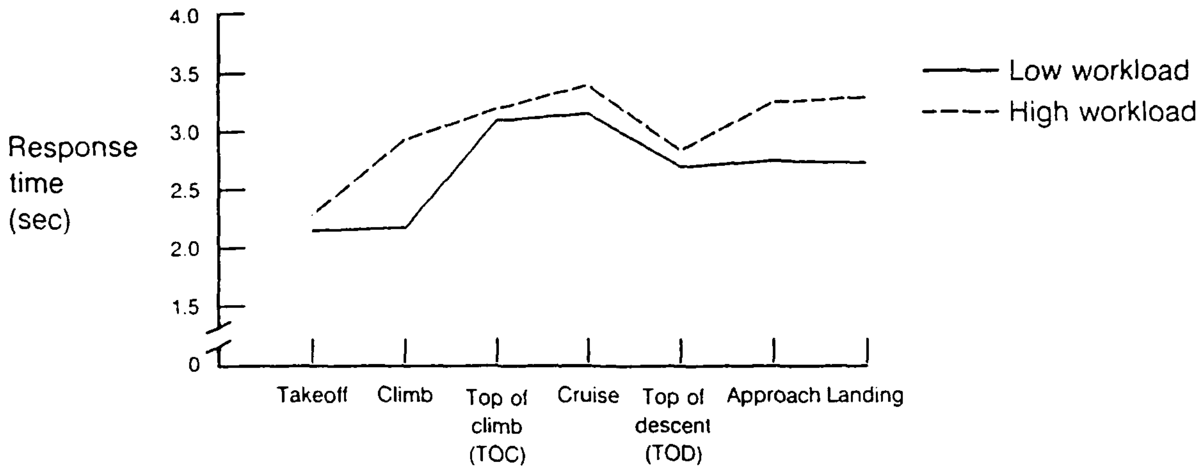


Table 7.2.2.3-7

Secondary Task (Response Time)

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight Mean	SD	High-workload flight Mean	SD
Takeoff	2.15	(0.52)	2.29	(0.89)
Climb	2.71	(1.42)	2.93	(0.97)
Top of climb	3.09	(1.51)	3.19	(1.28)
Cruise	3.15	(1.51)	3.39	(1.79)
Top of descent	2.69	(0.87)	2.84	(0.73)
Approach	2.74	(1.22)	3.25	(1.51)
Landing	2.73	(1.00)	3.29	(1.64)

H1167 26 R5

Table 7.2.2.3-8

Secondary Task (Response Time)

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	---	---
Climb	r(1) = 0.26	---
Top of climb	r(5) = 0.37	r(6) = 0.02
Cruise	r(4) = 0.90	r(2) = 0.98
Top of descent	r(16) = 0.39	r(15) = 0.27
Approach	r(13) = 0.65*	r(10) = 0.62
Landing	r(3) = -0.21	---

*Significant

F 1167 87 RGrk

Figure 7.2.2.3-5

Secondary Task (Probe Accuracy - Percent Correct)

Part Task Simulation
Mean Scores

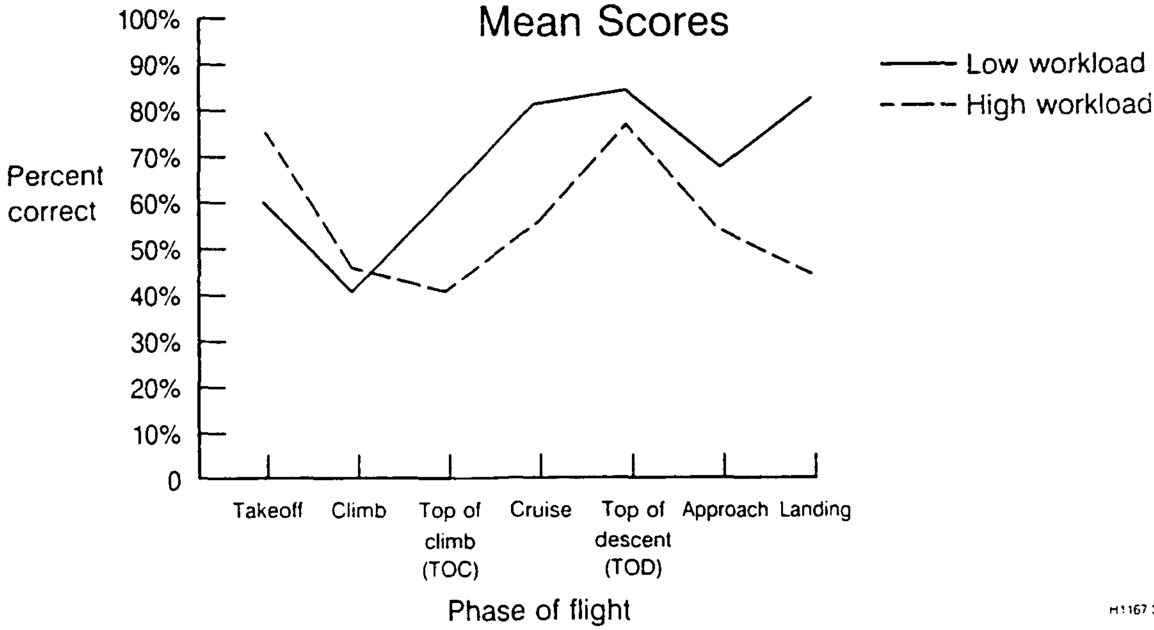


Table 7.2.2.3-9

Secondary Task (Probe Accuracy - Percent Correct)

Part Task Simulation Data
Means and Standard Deviations

Window	Low-workload flight		High-workload flight	
	Mean	SD	Mean	SD
Takeoff	60%	(55%)	75%	(45%)
Climb	41%	(44%)	46%	(49%)
Top of climb	61%	(34%)	41%	(36%)
Cruise	81%	(23%)	55%	(37%)
Top of descent	84%	(15%)	77%	(18%)
Approach	67%	(27%)	54%	(30%)
Landing	82%	(39%)	44%	(51%)

H1107 27 R3db

Table 7.2.2.3-10

Secondary Task (Probe Accuracy)

Part Task Simulation

Test-Retest

Reliability Correlations

Window	Low	High
Takeoff	---	---
Climb	r(1) = -0.10	---
Top of climb	r(5) = 0.35	r(6) = 0.28
Cruise	r(4) = 0.16	r(2) = 0.74
Top of descent	r(16) = 0.51	r(18) = 0.04
Approach	r(13) = 0.60	r(10) = -0.06
Landing	---	---

F 1167 86 H4rs

Table 7.3-1

Correlation Matrix

Part-Task Simulation

	ABP	ARS	EBK	HRM	HRSD	STRT%	WHL	STK	PED	SWAT	TLX
ABP	1.0000										
ARS	0.2057	1.0000									
EBK	0.1273	-0.0265	1.0000								
HRM	0.5024	-0.4998	-0.2454	1.0000							
HRSD	0.2329	**0.6724**	0.4533	-0.4245	1.0000						
STRT%	0.4331	-0.1771	0.2480	0.2071	0.0314	1.0000					
WHL	-0.1636	**0.8485**	-0.0077	-0.6442	**0.6637**	-0.4691	1.0000				
STK	-0.2159	**0.7195**	0.2553	**-0.7964**	**0.7261**	-0.2672	**0.8948**	1.0000			
PED	-0.5366	-0.0616	0.6155	**-0.7383**	0.2645	0.0426	0.1695	0.4735	1.0000		
SWAT	0.0375	**0.6888**	-0.0154	-0.4376	0.3008	-0.5519	**0.6806**	0.5536	-0.0875	1.0000	
TLX	0.0903	0.6227	-0.1087	-0.3055	0.1970	-0.4843	0.5858	0.4486	-0.2097	**0.9708**	1.0000
OWS	0.0559	**0.6644**	-0.0466	-0.4077	0.2595	-0.4609	0.6256	0.5287	-0.1052	**0.9760**	**0.9897**
STRT	0.5182	0.5569	0.0048	0.0273	0.3938	-0.3536	0.5647	0.4182	-0.3337	0.5734	0.5437
VISUAL	**-0.9080**	-0.0645	-0.1039	-0.5625	0.0461	-0.4746	0.3388	0.3832	0.5394	0.0399	-0.0351
MANLEFT	**-0.8651**	0.1155	-0.0319	-0.6536	-0.0545	-0.1961	0.3585	0.4252	0.5854	0.0537	0.0108
MANRIGHT	-0.3869	0.3076	0.1112	-0.5537	0.3849	-0.5107	0.5461	0.5997	0.3938	0.4909	0.3939
VERBAL	-0.0370	0.1233	-0.3918	0.1576	-0.2230	-0.3001	0.0914	-0.1316	-0.4676	0.5083	0.6334
AUDITORY	-0.4410	-0.0722	-0.4748	0.1297	-0.2204	-0.4934	0.1514	-0.0662	-0.3035	0.2082	0.2767
COGN'TVE	**-0.6576**	-0.2581	-0.4157	-0.0405	-0.4789	-0.5414	-0.0088	-0.1165	-0.0357	0.1974	0.2407

Critical correlation values are r(12) = 0.66 or r(12) = -0.66 are in **bold**

H1167.02

Table 7.3-2

Correlation Matrix

Part-Task Simulation

	OWS	STRT	VISUAL	MANLEFT	MANRIGHT	VERBAL	AUDITORY	COGN'TVE
OWS	1.0000							
STRT	0.5195	1.0000						
VISUAL	0.0075	-0.3953	1.0000					
MANLEFT	0.0655	-0.4279	**0.7417**	1.0000				
MANRIGHT	0.4575	0.1243	0.6388	0.2827	1.0000			
VERBAL	0.5674	0.0078	0.1045	-0.0078	0.2079	1.0000		
AUDITORY	0.2191	-0.1492	0.5469	0.2519	0.3802	**0.7784**	1.0000	
COGN'TVE	0.2096	-0.3358	0.6539	0.4240	0.4868	0.6496	**0.8514**	1.0000

Variable Labels

HRM	Average Interbeat Interval
HRSD	Standard Deviation for Average Interbeat Interval
ABP	Power Spectral Analysis Blood Pressure component from heart rate
ARS	Power Spectral Analysis Respiration component from heart rate
EBK	Eye blinks per minute
WHL	Wheel control input (aileron) per minute
STK	Column control input (elevator) per minute
PDL	Pedal control input (rudder) per minute
SWAT	Subjective Workload Assessment Technique
TLX	NASA Task Load Index
OWS	1-to-20 point overall workload score
STRT	Secondary Task Reaction Time
STRT%	Probe Accuracy, to positive probes, for Secondary Task

Boeing Time Line Analysis

VISUAL	-- Eyes	MANLEFT	-- Left side of body
VERBAL	-- Spoken communication	MANRIGHT	-- Right side of body
AUDITORY	-- Listening by flightcrew	COGN'TVE	-- Cognitive channel

H1167.03 R2rs

Critical correlation values are r(12) = 0.66 or r(12) = -0.66 are in **bold** flight (7 each from the low and high workload conditions) in order to determine common "underlying" dimensions among the workload measures.

Principal Component Analysis is a form of Factor Analysis that maximizes the variance accounted for in the solution. Principal Component Analysis (PCA) sorts the measures into factor loadings by maximizing the amount of variation that can be explained by each factor, and then calculates a "loading" for each variable on the respective factors. The loading is a score between +1 and -1, similar to a correlation coefficient, where the absolute value indicates the strength of the loading and the sign (plus or minus) indicates the direction of the relationship.

The "naming" of the factors which emerge from any Factor Analysis can be the subject of much debate. The investigators in this project developed the following labels:

FACTOR 1 - Gross Motor Activity.

FACTOR 2 - Psycho-motor Activity (i.e., Flight Path Control).

FACTOR 3 - Cognitive Activity (i.e., Operation and Monitoring of Aircraft Engines and Systems).

FACTOR 4 - Mediational Activity (i.e., Command Decisions).

When selecting measures for a aircraft certification program measures should be selected that represent various FACTORS, as opposed to selecting measures from various domains (i.e., Subjective, Physiological, and Performance). In that way the various components of workload could be quantitatively assessed, otherwise two measures from various domains which assess the same underlying dimension might be brought to bear in the assessment effort.

Caution should be exercised when evaluating the PCA table because the variables included in the analysis has an effect on the factors and the loadings. If variables were to be left out of the analysis it is likely that the factor loading scores would change for the variables.

The PCA table that follows shows which measures load on common dimensions (Table 7.4-1). Factor loadings less than plus or minus 0.25 are deleted to ease in the reading of the PCA table.

7.5 DISCUSSION

The intent of our program is to examine existing workload measures to determine the validity and reliability of the application of these measures to new aircraft certification under FAR 25.1523. In pursuit of the stated goal each workload measure has been treated as if it were the only measure being examined in this project. There are two reasons why we are using this approach. First, it was never our goal to develop a battery of workload measures to be utilized in commercial aircraft certification. It was our intent to subject each of the candidate workload measures to the rigors of full fidelity simulation testing in order to examine the constructs of validity and reliability. Second, the measures are examined individually because this is conceptually the only practical manner to assimilate all the data presented.

In order to provide quick look summaries of the data two tables have been compiled. The first table summarizes the empirical findings of validity and reliability (Table 7.5-1).

Table 7.4-1

Principal Component Analysis

Part-Task Simulation Data

Sorted rotated factor loadings (pattern)

	Factor 1	Factor 2	Factor 3	Factor 4
Visual (TLA)	0.967			
Blood pres.	-0.960			
Manual left (TLA)	0.864			
Average IBI	-0.626	-0.538		-0.409
Cognition (TLA)	0.623	-0.401	0.488	-0.425
Manual right (TLA)	0.565	0.329	0.456	
Wheel control input	0.281	0.898	0.287	
Respiration		0.866	0.301	
Stick control input	0.371	0.845		
IBI variability		0.774		0.338
Sec. task react. time	-0.485	0.663	0.293	
NASA task load index		0.388	0.892	
Overall workload score		0.439	0.870	
SWAT		0.498	0.843	
Verbal (TLA)			0.795	-0.406
Eye blink				0.898
Pedal control input	0.646			0.709
Audition (TLA)	0.426		0.456	-0.624
Sec. task percent cor.	-0.385		-0.464	0.397
VP	4.914	4.666	4.115	2.610

The above factor loading matrix has been rearranged so that the columns appear in decreasing order of variance explained by the factors. The rows have been rearranged so that for each successive factor, loadings greater than 0.500 appear first. Loadings less than 0.25 have been blanked.

H1167.2!

Table 7.5-1

PART - TASK SIMULATION	SUBJECTIVE			PHYSIOLOGICAL					PERFORMANCE				
	SWAT	TLX	OWS	EB	HR	HRV	SBP	SRS	WHEEL	COLUMN	PEDAL	STRT	STPA
VALIDITY													
WORKLOAD DISCRIMINATION FLGHT MAIN EFFECT ANOVA	YES	YES	YES	NO	YES	NO	NO	YES	N/A	N/A	N/A	N/A	N/A
LOW-HIGH WORKLOAD COMPARISON PER WINDOW (7 possible)	2	3	3	0	5	0	0	2	5	4	0	1	0
PHASE OF FLIGHT DISCRIMINATION LOW WORKLOAD ANOVA	NO	NO	NO	YES	YES	YES	YES	YES	N/A	N/A	N/A	N/A	N/A
INDIVIDUAL PHASE OF FLIGHT COMPARISONS LOW WORKLOAD Newman-Kuels (21 possible)	0	0	0	3	14	0	7	0	N/A	N/A	N/A	N/A	N/A
PHASE OF FLIGHT DISCRIMINATION HIGH WORKLOAD ANOVA	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	N/A	N/A
INDIVIDUAL PHASE OF FLIGHT COMPARISONS HIGH WORKLOAD Newman-Kuels (21 possible)	3	4	5	6	9	10	1	0	10	9	11	N/A	N/A
RELIABILITY													
TEST-RETEST CORRELATIONS Day 1 to Day 2 (14 possible)	4	4	4	7	6	5	3	5	11	10	6	1	0
INTER-RATER AGREEMENT Each Pilot to Group Average	78%	78%	78%	56%	78%	44%	17%	28%	N/A	N/A	N/A	N/A	N/A

SWAT - SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE
TLX - NASA TASK LOAD INDEX
OWS - OVERALL WORKLOAD SCALE

EB - EYEBLINK RATE (BLINKS PER MINUTE)
HR - HEART RATE IN INTERBEAT INTERVAL (IBI)
HRV - STANDARD DEVIATION OF IBI
SBP - POWER SPECTRAL ANALYSIS (BLOOD PRESSURE COMPONENT)
SRS - POWER SPECTRAL ANALYSIS (RESPIRATION COMPONENT)

WHEEL - WHEEL CONROL INPUT (PER MINUTE)
COLUMN - COLUMN CONTROL INPUT (PER MINUTE)
PEDAL - PEDAL CONTROL INPUT (PER MINUTE)
STRT - SECONDARY TASK (RESPONSE TIME)
STPA - SECONDARY TASK (PROBE ACCURACY)

The second table presents the rank ordering of the phases of flight for each workload measure (Tables 7.5-2 and 7.5-3).

7.5.1 DISCUSSION OF VALIDITY AND RELIABILITY RESULTS

SUBJECTIVE

The subjective measures demonstrate validity and reliability, although SWAT was weaker than the other two measures in terms of reliability. The authors feel that the low overhead in terms of implementation and data reduction for subjective measures add to the attractiveness of utilizing these types of measures in an aircraft certification effort.

The Pilot Subjective Evaluation (PSE) technique developed by Boeing could not be utilized in the current study due to the baseline versus new aircraft comparison inherent in the PSE. Although the criteria of the present study could not be brought to bear on the PSE, the dividend of identification of specific subsystems which are influenced by the functions and factors of FAR 25.1523 Appendix D, is of enormous benefit in an aircraft certification effort (Fadden, 1982; Fadden and Ruggerio, 1987).

PHYSIOLOGICAL

The physiological measures were perhaps the most disappointing in terms of the ability to discriminate levels of workload in a reliable manner.

Horizontal EOG was collected in order to analyze eye movement. Eye Movement per unit of time may be a useful index of workload, but resource limitations did not allow for a careful reduction of the horizontal EOG data so no analyses were conducted. Eyeblink, although reliable, could not discriminate the different workload conditions. The lack of a main effect for eyeblink may be due to the different visual task demands in the phases of flight inherent in commercial transport aircraft operations. Certain phases of flight can be characterized by a great deal of chart reading, others by the intense scan of instruments on an approach, yet others by quick scans at various system instruments (both on the forward instrument panel and the flight engineer's panel) to diagnose system malfunctions.

Inter-beat interval (mean Heart Rate) was a fairly robust measure in terms of validity and reliability. We are still concerned about the ability to tease arousal and workload apart when using a measure such as Heart Rate. Due to the sensitivity of Heart Rate to arousal we feel the same pattern of results that were found for Heart Rate might be found for an observer riding in the jumpseat in the cockpit. No attempt is being made to impugn the reputation of Heart Rate with regards to it's utility as a workload measure, rather a word of caution is being advanced.

Heart Rate Variability (standard deviation of the Inter-beat Interval) was not able to discriminate between the low and high workload conditions. Test/retest reliability was good, but the utility of reliable measure which cannot discriminate between low and high workload is questioned.

The Blood Pressure Component of the power spectral analysis could not discriminate between the low and high workload conditions. A few of the test/retest reliability correlations were significant, but of no real value since the measure did not demonstrate discriminability.

Table 7.5-2

Part-Task Simulation (Rank Order of Phase of Flight)

LOW WORKLOAD FLIGHT

PHASE OF FLIGHT	SWAT LOW	TLX LOW	OWS LOW	EYEBLINK LOW	IBI LOW	IBI SD LOW	B.P. LOW	RESP. LOW	WHEEL LOW
Takeoff	3	2	2	3	6	2	6	7	2
Climb	5	6	4	6	2	1	7	5	5
Top of Climb	2	4	3.5	7	4	5	3	4	4
Cruise	1	1	1	2	1	3	1	6	1
Top of Descent	4	5	5	5	3	4	2	3	3
Approach	6	3	3.5	4	5	6	4	2	6
Landing	7	7	6	1	7	7	5	1	7

PHASE OF FLIGHT	COLUMN LOW	PEDAL LOW	ST RT LOW	ST PA LOW	COGNITIVE LOW	AUDITORY LOW	VERBAL LOW	MAN RIGHT LOW	MAN LEFT LOW	VISUAL LOW
Takeoff	4	7	1	6	6	4	4.5	5	7	6
Climb	3	5	3	7	7	7	6	6	5	7
Top of Climb	5	3	6	5	3	2	2.5	2.5	1.5	3
Cruise	1	1	7	3	1	1	1	1	1.5	1
Top of Descent	2	2	2	1	5	6	7	2.5	3	2
Approach	6	4	5	4	2	5	4.5	4	4	4
Landing	7	6	4	2	4	3	2.5	7	6	5

Table 7.5-3

Part-Task Simulation (Rank Order of Phase of Flight)

HIGH WORKLOAD FLIGHT

PHASE OF FLIGHT	SWAT HIGH	TLX HIGH	OWS HIGH	EYEBLINK HIGH	IBI HIGH	IBI SD HIGH	B.P. HIGH	RESP. HIGH	WHEEL HIGH
Takeoff	1	1	1	2	5	1	7	7	1
Climb	2	3	2	5	1	2	6	6	3
Top of Climb	7	7	7	4	4	5	2	4	4
Cruise	6	6	6	3	2	4	1	5	2
Top of Descent	3	5	5	6	3	6	3	3	5
Approach	5	4	4	7	6	3	4	1	6
Landing	4	2	3	1	7	7	5	2	7

PHASE OF FLIGHT	COLUMN HIGH	PEDAL HIGH	ST RT HIGH	ST PA HIGH	COGNITIVE HIGH	AUDITORY HIGH	VERBAL HIGH	MAN RIGHT HIGH	MAN LEFT HIGH	VISUAL HIGH
Takeoff	1	6	1	2	5	2	2.5	4	7	5
Climb	4	2	3	5	7	7	6	5	4	6.5
Top of Climb	5	4	4	7	6	6	7	7	2	4
Cruise	2	1	7	3	1	1	4	1	1	1
Top of Descent	3	3	2	1	4	5	5	3	5	2
Approach	6	5	5	4	2	3	2.5	2	3	3
Landing	7	7	6	6	3	4	1	6	6	6.5

An anomalous finding for the Respiration Component of the power spectral analysis is hard to reconcile. The a priori prediction for the respiration component is that as workload goes up the power in the respiration portion of the spectrum should go down. prn
The finding that the respiration component increases with increasing workload warrants careful examination of the measure in the next simulation effort.

PERFORMANCE

The discriminability and reliability of the wheel (aileron) and column (elevator) control input activity performance variables was very good. A number of aircraft state variables were collected and analyzed for the Part-Task simulation included:

(a) RMS flight director error in the lateral and vertical direction,
(b) Throttle activity,
(c) Altitude error over the middle and inner marker (during the approach and landing),
(d) Lateral deviation from runway centerline (during the approach and landing),
(e) Localizer and glideslope deviation for the #1 and #2 receivers.

Only the control input activities demonstrated any validity by discriminating between the low and high workload flights.

The lack of validity and reliability results for the Secondary Task does not necessarily mean it is a poor index of workload, rather it points out the unsuitable nature of the measure for assessing workload in commercial transport operations. In the implementation of the Secondary Task in the Part-Task simulation a great deal of secondary variance was generated for Response Time due to the fact that commercial pilots rarely keep their hand on the PTT switch on the yoke. Therefore longer reaction times were found for relatively low periods of workload because the pilot had to literally reach for the PTT switch to complete a response. In a military aircraft, particularly those designed with a HOTAS concept (hands on throttle and stick), the implementation of this sort of secondary task would not be subject to the source of secondary variance found in the Part-Task simulation.

7.5.2 DISCUSSION OF CORRELATION MATRIX

The subjective measures demonstrate a high inter-correlation, indicating that they are influenced by the same changes in task demands.

The Blood Pressure component's high correlation to control input activity is what would be expected if both measures are tapping some sort of physical component of workload.

A summary of the most notable findings from the correlation matrix include:

(a) The subjective ratings are significantly inter-correlated ($r=0.97$ being the smallest correlation).
(b) The negative correlation of inter-beat interval and various indices of physical workload (e.g., column & pedal control) is significant.
(c) A number of correlations approach significance between IBI and wheel control inputs, SWAT, NASA-TLX, the 1-to-20 point overall workload score, and the visual, manual left and right from the TLA.

(d) Some findings are unexpected from the examination of the correlation matrix. The respiration component of the Power Spectral analysis is positively correlated with the subjective ratings and control inputs.

8.0 WORKSHOP TWO (SEATTLE, WA.)

8.1 OBJECTIVES

Workshop number two was conducted in order to present the results from the Part-Task simulation, and obtain recommendations for improvements for the Full-Mission simulation.

Participants were asked to comment on the fidelity of the simulation scenarios and the applicability of the candidate workload measures to aircraft certification. The Full-Mission simulation test plan was presented for review. Audience comments were reviewed and revisions to the test plan were incorporated prior to the Full-Mission simulation.

8.2 ATTENDEES

Eighty attendees were drawn from a wide cross-section of operational personnel and potential workload measurement users. University scientists from the first workshop were invited to attend to help assess the scientific quality of the test design, the results, and the appropriateness of the conclusions drawn from the data. The remainder of the attendees were from aerospace industry, government regulatory agencies, military workload experts, and NASA.

8.3 DESCRIPTION OF EVENTS

The first day of the workshop was spent reviewing the methodology and results from the Part-Task simulation. The second day was spent reviewing "lessons learned" from the Part-Task simulation and appropriate changes to be incorporated into the Full-Mission simulation.

The proceedings of Workshop number two includes copies of all the workshop presentations (Boucek et. al., 1988). The data collected in Part-Task testing and the results of the Timeline Analysis were included. In addition, a summary of the discussions held over the two days was provided. It included pertinent points made by the audience that were considered for the full-mission simulation.

8.4 RESULTS

Aside from presenting the results from the Part-task simulation, the most important reason for holding Workshop Two was to gather comments and suggestions for improvements on the simulation testing for the Full-mission simulation. The most important topics are discussed below:

<u>IMPLEMENTATION OF A WORKLOAD MEASURE</u>

The feasibility of using a decision-tree based a workload scale, in addition to the other subjective measures taken, was discussed. The possibility of using a "Modified Cooper-Harper" or the "Bedford Scale " was addressed. The principle motivation was to use a subjective rating technique with empirical evidence of validity and reliability. The 1-to-20 point overall workload scale used in the Part-Task simulation was an extension of the NASA-TLX methodology, and did not possess an empirical record of the other subjective rating methods.

IN-FLIGHT RATING

A number of suggestions were made regarding an In-Flight subjective measure to provide opportunity for a comparison of In-Flight versus Post-Flight subjective assessment.

The question of which rating scale should be employed in the simulation was discussed. SWAT scores can be taken verbally using verbal probes was the most feasible. Although it is feasible to implement any subjective rating verbally during flight, SWAT was deemed the easiest due to the smallest rating scale (e.g., 3 point: low, medium, and high). The Bedford and Modified Cooper-Harper scales both contain 10 point rating scales, while the NASA-TLX contains 20 point rating scales.

The question of when the ratings would be taken In-Flight was also raised. If the ratings were requested at the end of the measurement windows, and the measurement window was specifically demarcated, then pilots might modify their flying performance, or in some fashion affect the other workload measures being collected. Demarcation of the measurement window had to be avoided otherwise the pilot might change his performance (i.e., try harder) at specific times because he knows he is being measured. It was suggested that measurements be taken at variable intervals, both during and outside of measurement windows. The problem with "random" probing is the lack of empirical comparison available due to data collected outside of the measurement windows. It was decided to collect data at the end of the measurement window. The problem with the "instantaneous" probing at the end of the window is that the event rating would reflect only the workload at that particular moment and not the workload of the whole measurement period (i.e., the measurement window). The final decision to probe for an "instantaneous" rating was based on not wanting the In-Flight probe to artifact the other workload measures being collected concurrently.

SECONDARY-TASK ADMINISTRATION

It was decided to eliminate the secondary task from the Full-mission simulation. The design of the secondary task was discussed in length. Flight operations personnel questioned the implementation of the secondary task in the flight test portion of certification. It was determined, however, that the secondary task may be valuable even if it can only be used in simulation. Even though it was handicapped during the part-task testing by problems that were encountered, response time showed a trend for workload discriminability.

Too many problems were encountered in the Part-task simulation with the secondary task. The push-to-talk (PTT) switch used by the pilot to respond to the positive probes blanked ATC with the switch closure. The feasibility of using a different switch was discussed. Several other types of "response to a probe" task were suggested (e.g., squawking different transponder codes) for use as a secondary task measure. The suggested tasks lacked the requirements of both positive and negative probes, and a sufficient number of probes to gather a good base of data. Since data is collected on the Captain only, the task must also be one that is normally performed by the Captain.

Other aircraft environments (e.g., tactical) can more readily adapt a secondary task methodology. The reaction to ground threats using voice activated counter-measures has shown a great deal of promise (Vidulich and Bortolussi, 1988).

USE OF AUTOPILOT

For the Full-mission simulation it was decided to dispatch the aircraft with the autopilot INOP for all the flights in order to be able to interpret the control input activity measures. In Part-Task simulation testing, the use of the autopilot in the low workload condition was left to the pilot's discretion, and thus, its use became inconsistent across the subject population. It was felt that tighter control on the use of autopilot (or preventing its use altogether) in Full-Mission testing should be required.

INCAPACITATION

In order to manipulate the FAR 25.1523 Appendix D, factors of crew member unavailable at crew station and incapacitation a feigned incapacitation on the part of the confederate First Officer was discussed. Discussion centered around the possibility of a negative reaction by the subject pilot. It might not be immediately obvious that the First Officer's incapacitation was part of the simulation scenario, and the pilot might interrupt the simulation to seek aid for the stricken crew member.

In order to selectively manipulate the Captain's task demands similar to the increased loading of a First Officer's incapacitation it was decided that on one flight the Captain would be required to tune and talk on the command radio.

WORKLOAD MEASURES TO BE USED IN THE FULL-MISSION SIMULATION

Because of inputs (discussed in the previous section) from the attendees at Workshop Two the following measures were selected for the Full-Mission simulation tests to be conducted at NASA-Ames:

SUBJECTIVE

- SWAT (In-flight)
- SWAT (Post-flight)
- Bedford (Post-flight)

PHYSIOLOGICAL

- Heart Rate (Inter-beat interval)
- Heart Rate Variability (Standard deviation of IBI)
- Mulder Analysis for Blood Pressure
- Mulder Analysis for Respiration
- Eyeblink Rate

PERFORMANCE

Primary Task
- Control Inputs
  - Wheel
  - Column
  - Pedals

Secondary Task
- None

9.0 FULL-MISSION SIMULATION TESTING

Again the simulation was performed at the NASA-Ames Research Center, Moffett Field, California. Air-Traffic Control was again simulated to ensure that the fidelity was as close to real-world conditions as possible.

9.1 METHOD

Similar to the Part-task simulation tests, only Captains were used for the simulation. Again, no attempt was made to address crew performance from a cockpit resource management viewpoint.

9.1.1 SUBJECTS

PILOTS

Sixteen Airline Transport Pilots (ATP), (from American, United, TWA, and Eastern), served as subjects in the experiment. Subjects were all male ranging in age from 44 to 58. Subjects were either currently FAR Part 121 qualified as Captain for the B-727 or had spent 5 years of duty as Captain for the B-727.

FLIGHT CREW

Two confederates participated in the simulation study as the First Officer and Flight Engineer, respectively. Preston Sult, Flight Crew Training at Boeing Commercial Airplanes, served as the First Officer in the study. Preston also gave the briefing on differences training and the routes to be flown in the study. Doranne VonEnde and Hugh Campion, both qualified flight engineers, served as Flight Engineers in the study. Both the First Officer and Flight Engineer were cognizant of the workload manipulations a priori, and attempted to give each pilot similar treatment during the simulation.

9.1.2 EXPERIMENTAL DESIGN

The factors that drove the design included:

a. Different levels of workload as defined by the functions and factors of FAR 25.1523 Appendix D.
b. Two test sessions in order to evaluate reliability.
c. Sampling of various phases of flight in order to represent task demands representative of operational conditions.

9.1.2.1 INDEPENDENT VARIABLES

TEST/RETEST

Similar to the Part-task simulation a test/retest methodology was employed to evaluate the reliability of the workload measures. The period between the two simulation test periods was at least 27 days, and was as long 70 days.

LEVELS OF WORKLOAD

Three different flight scenarios were used to test functions and factors of FAR 25.1523 Appendix D, in the Full-Mission simulation. The two short hops from the Part-Task simulation were carried over, as well as a longer (1 hour 30 minute) flight.

No effect was found for route flown during the Part-Task simulation. In the present study there was no attempt made to counter-balance route (SFO-SCK, SMF-SFO, & LAX-SFO-OAK-SMF) and workload conditions (Nominal, Communication, and Malfunction).

The SFO-SCK flight is a "Nominal" workload flight. The autopilot is MEL, as it is for all the flights, but otherwise the conditions are ideal. An ILS approach and landing occurs at SCK.

The SMF-SFO flight is the "Communication" flight. In order to simulate the duties of the Pilot Flying (PF) in a two crew cockpit in which the PNF is occupied (or out of the cockpit area) with other duties, the PF must tune and talk on the command radio from takeoff through landing. Other than the "communication" manipulation the copilot and flight engineer perform their normal flight duties. An ILS approach and landing occurs at SFO.

The LAX-(SFO)-(OAK)-SMF flight is the "Malfunction" flight. During the flight (between windows 3 and 4) the crew receives a message (company contact using SELCAL) that SFO has closed because of a power failure, and they are requested to divert to OAK. The weather at OAK is marginal, going below minimums as the crew approaches the middle marker. At decision height the runway is not visible and a missed approach is executed. Passing 2,000 feet on the missed approach the number one engine fails. One minute after passing 6,800 feet, during the climb to 7,000 feet, the "A" hydraulic system loses pressure and quantity until complete failure ensues. The crew continues the climb to their enroute altitude of 7,000 feet for the remainder of the flight to the alternate, SMF. The crew continues the flight to an ILS approach and landing in good weather at SMF.

A table is provided that contains a summary of the workload manipulations in order to aid the reader in understanding the different task demands for the low and high workload flights (Table 9.1.2.1-1).

PHASES OF FLIGHT

Seven phases of flight were examined in the simulation test.

(a) Takeoff
(b) Climb
(c) Top of Climb (TOC)
(d) Cruise
(e) Top of Descent (TOD)
(f) Approach
(g) Landing (or Missed Approach)

Eleven phases of flight were examined in the malfunction flight, the same seven as listed above plus the four segments listed below.

(h) #1 Engine Failure
(i) "A" System Hydraulic
(j) Approach
(k) Landing

All the flights contain seven measurement "windows" in common, additionally, the long flight contains an additional four measurement windows:

Table 9.1.2.1-1

Full-Mission Simulation

Workload Levels

Conditions	Level		
	High (LAX → SFO → OAK → SMF)	Low (SFO → SCK)	Incapacitation (SMF → SFO)
Weather	LAX: Ceiling 500 ft; visibility, 3 mi OAK: Ceiling 200 ft; RVR zero SMF: Clear, visibility 15 mi	Clear	Clear
Wind	LAX: Calm OAK: Calm SMF: 340 at 10 kn	Calm	Calm
Non-normals	• "A" system hydraulic low pressure light illuminated • Number three engine flameout • Hydraulic system "A" failure	None	F/O Incapacitation

DL1167.08

WINDOW	OPENING EVENT	CLOSING EVENT
(a) TAKEOFF	E.P.R. > 1.5	Flaps 5 degrees
(b) CLIMB	Flaps up	1 Minute later
(c) TOP OF CLIMB	10,000 feet	2 Minutes later
(d) CRUISE	3 Minutes after 10,000 feet	2 Minutes later
(e) TOP OF DESCENT	Throttles to idle	2 Minutes later
(f) APPROACH	Localizer Activation	Outer Marker
(g) LANDING	Middle Marker (or MISSED APPROACH) (for the long flight)	30 Seconds
(h) ENGINE FAILURE	2,000 feet after Middle Marker	2 Minutes later
(i) "A" SYSTEM HYDRAULIC FAILURE	1 Minute after 6,800 feet	2 Minutes later
(j) APPROACH	Localizer Activation	Outer Marker
(k) LANDING	Middle Marker	30 Seconds later

Two graphics are provided to illustrate the flight scenarios pictorially in order to aid the reader in understanding the measurement windows (Figures 9.1.2.1-1 and 9.1.2.1-2).

As was the case with the Part-Task simulation, window and phase of flight are used as synonyms. Window is used when referring to experimental design or measurement, and phase of flight is used when discussing results.

Some changes were made to the length of the windows based upon the testing experience from the Part-Task simulation. Many of the windows were made a common length (2 minutes) to facilitate data reduction. The most notable change was the shortening of the landing window. In the Part-Task simulation the Landing window (1 minute 30 seconds) often found the pilot "sitting" on the runway for 45 seconds to 1 minute, waiting for the measurement period to end. In the Full-Mission simulation the landing window was shortened (30 seconds), and more accurately reflected only the activities involved with landing the aircraft.

SIMULATION SCHEDULE

Again a test/retest method was used to evaluate the reliability of the workload measures. The period between the two simulation test sessions was at least three months for every subject tested, and much longer in many cases. Pilots flew three scenarios, a Nominal, Communication, and Malfunction flight on both visits. In the present study no attempt

Figure 9.1.2.1-1

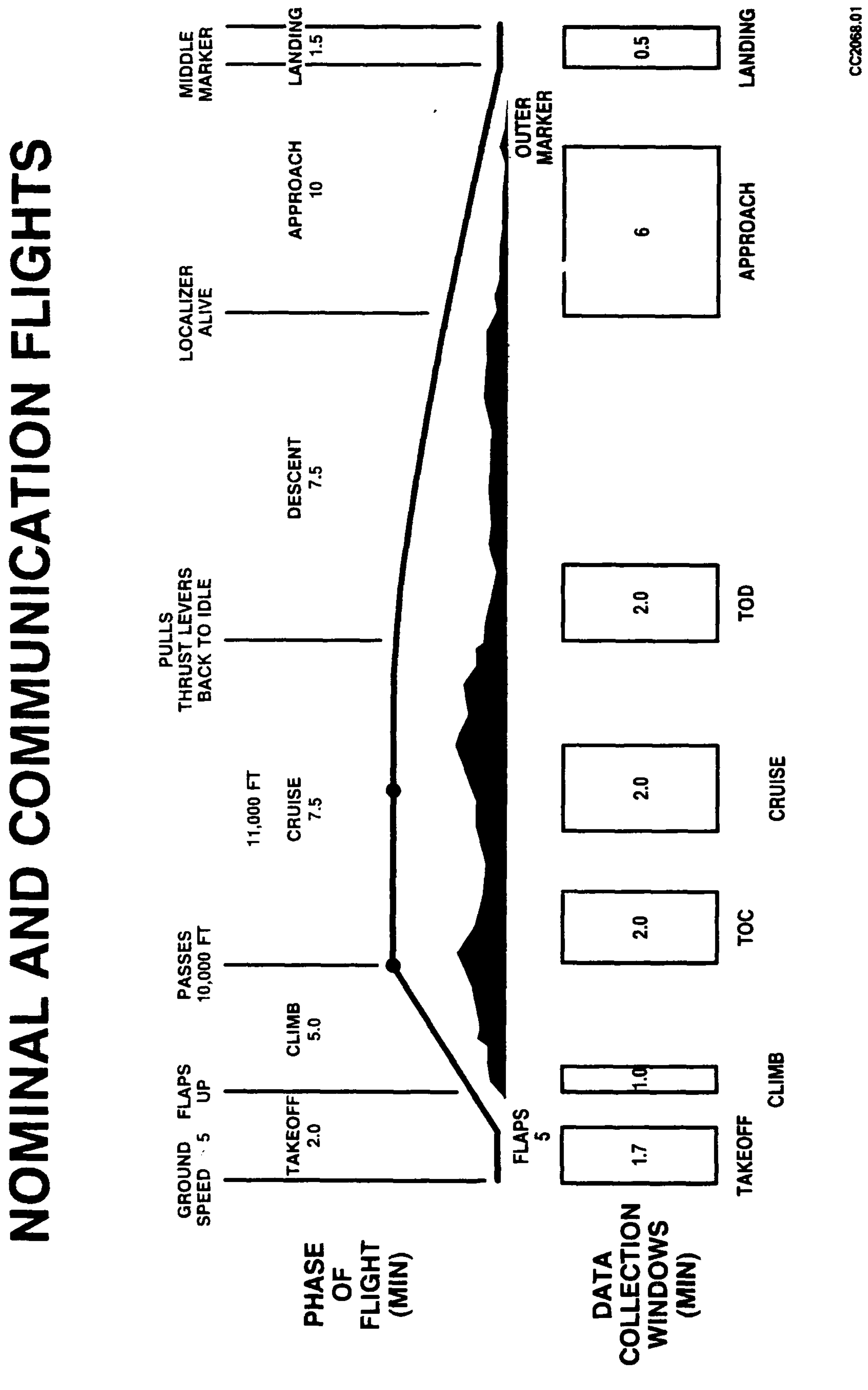
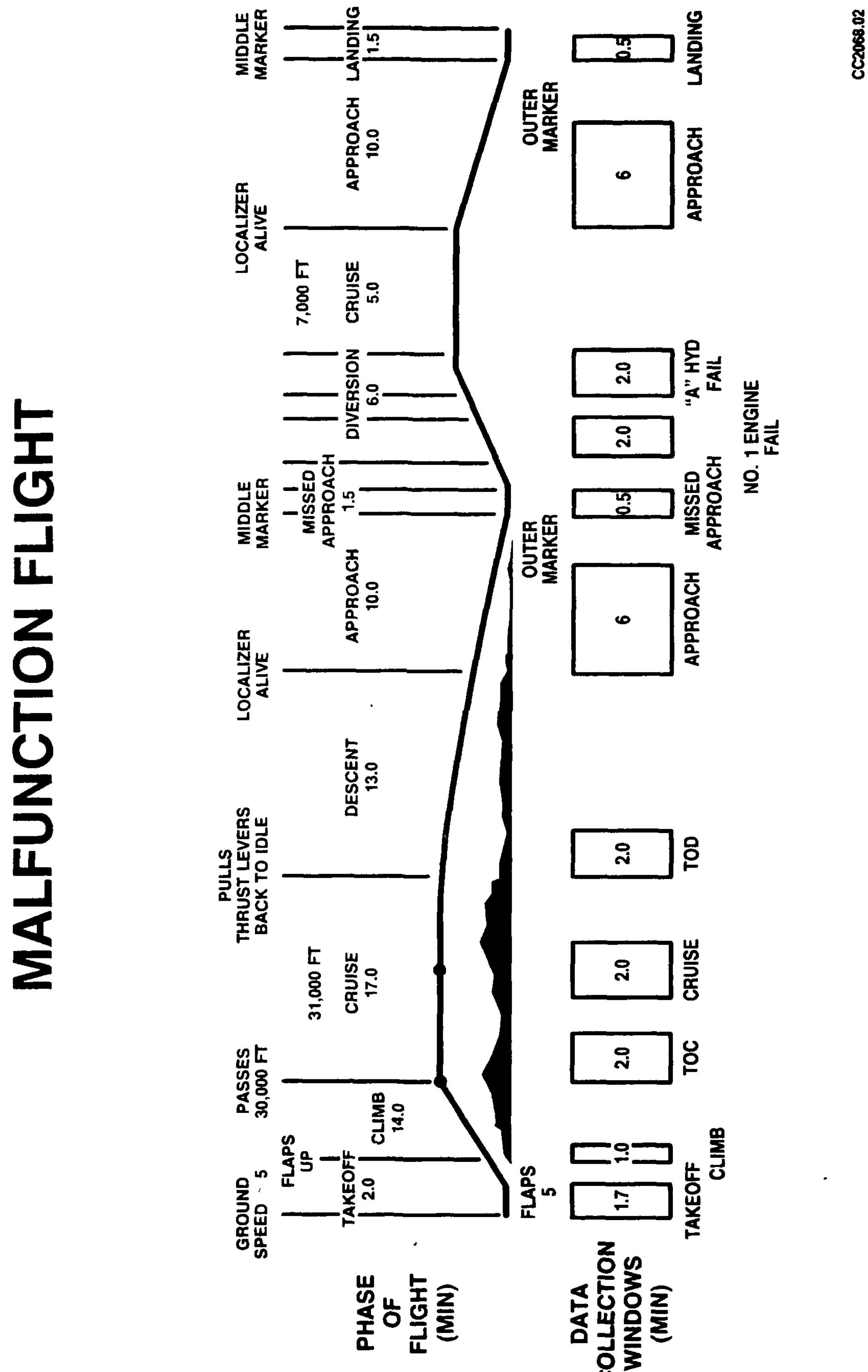


Figure 9.1.2.1-2



was made to counter-balance route and workload conditions (Nominal, Communication, and Malfunction).

9.1.2.2 DEPENDENT VARIABLES

SUBJECTIVE RATING

SWAT (In-Flight and Post-Flight) and the Bedford rating scale (Figure 9.1.2.2-1) were used in the Full-Mission simulation.

The In-Flight implementation of SWAT was accomplished by ATC probing the pilot for event ratings at the end of a measurement period. An example of a probe is, "TWA 241 give us your TIME, EFFORT, and STRESS rating." Pilots were instructed to give event ratings for the workload they were experiencing at the moment they were probed. When comparing the In-Flight ratings of SWAT to other workload measures it should be kept in mind that In-Flight SWAT ratings reflect an instantaneous assessment whereas the other measures reflect workload for the entire measurement period.

The Post-Flight subjective ratings, SWAT and Bedford, were collected using the same method as was employed in the Part-Task simulation. A video tape of the window was played for the pilot after all the simulation runs for the session were computed. When the measurement window was over the tape was stopped and the pilot made their ratings, first SWAT and then Bedford. When the subject had completed their rating of a single measurement window they were instructed to turn the page of their rating booklet, and asked not to refer to previous ratings.

PHYSIOLOGICAL INSTRUMENTATION

The physiological workload measures collected were the same as those used in the Part-task simulation: Eyeblink rate, Interbeat Interval, Standard Deviation of Interbeat Interval, Power Spectral Analysis (Blood Pressure and Respiration Component).

PERFORMANCE DATA

The performance measures collected were the same as those used in the Part-task simulation: control input activity for the wheel, column, and rudder pedals. The secondary task was dropped from the Full-mission simulation. All performance data was collected at a rate of 10 Hertz.

9.1.3 PROCEDURES AND EQUIPMENT

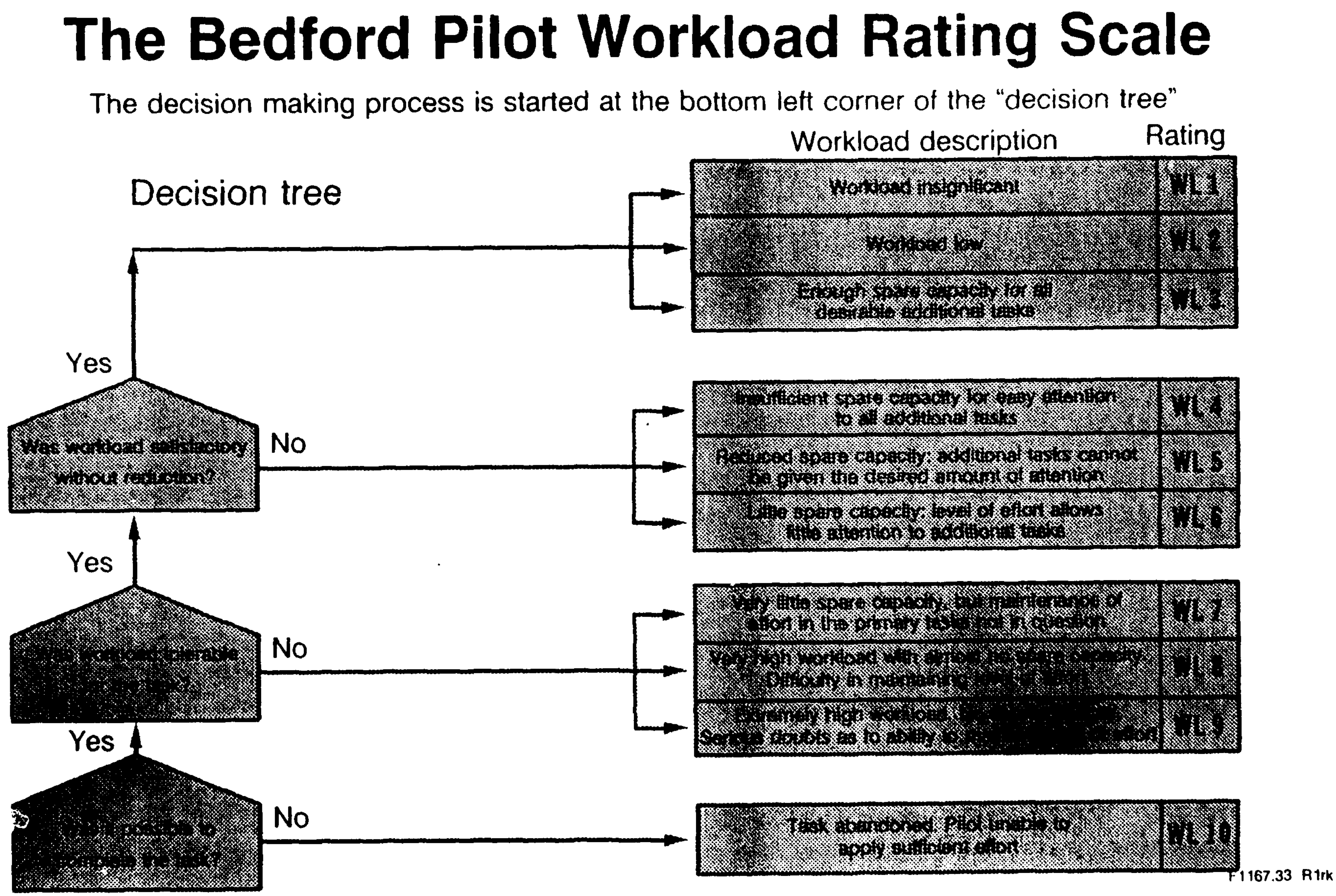
SIMULATOR

The Man-Vehicle System Research Facility's B-727 simulator was again used as the testbed for the following simulation study.

SCENARIO

There were three routes flown for the Full-Mission simulation. The routes were Sacramento to San Francisco (SMF-SFO), San Francisco to Stockton (SFO-SCK), and Los Angeles diverted from San Francisco to a missed approach at Oakland finally landing in Sacramento (LAX-SFO-OAK-SMF). The two short hop flights, (SMF-SFO) & (SFO-SCK) were flown at 11,000 feet enroute to the destination, for an ILS approach and landing. The long flight (LAX-SFO-OAK-SMF) is flown at 31,000 feet, enroute to San

Figure 9.1.2.2-1



Francisco there is a diversion to Oakland, where a missed approach is executed (owing to weather), followed by a diversion to a landing at the alternate, Sacramento.

Subjects received the same order of routes for session one and two. The presentation of flights was counter-balanced across pilots and is further discussed in the test order section. Subjects receive the same order of routes during testing for session one and two. The presentation of flights was counter-balanced across pilots.

9.1.4 STATISTICAL ANALYSES

A nominal alpha level of .01 was adopted for each statistical comparison, as was done in the Part-task simulation.

Predictions about the differences between the various flights was not confirmed in an a priori manner using the Boeing Timeline Analysis as was done in the Part-task simulation. The three flights were tailored to be extremely similar, except for the specific manipulation of FAR 25.1523 Appendix D functions and factors. Discriminability by a workload measure among the flights would indicate sensitivity of the measure to manipulations of the functions and factors of FAR 25.1523 Appendix D.

Again, a decision rules were established to determine if a given workload measure has demonstrated validity and reliability. The threshold chosen could generate an argument as to the appropriateness of the threshold, but the rule is necessary for a discussion of the "goodness" (validity and reliability) of the measure.

9.1.4.1 VALIDITY ANALYSES

For a workload measure to demonstrate validity it must discriminate among the various flights which manipulate the functions and factors of FAR 25.1523 Appendix D. An overall 2 X 3 X 7 repeated measures ANOVA was performed on each workload measure, with the factors of session (1 or 2), type of workload (Nominal, Communication, or Malfunction), and phase of flight, respectively. Separate, pair-wise, comparisons among the flights were then conducted in order to examine differences in workload predicted a priori based on different FAR 25.1523 Appendix D, tasks included in the different flights.

The analyses of the Full-Mission simulation have an additional complication in that there are three levels of workload, as opposed to the low and high of the Part-Task simulation. Just as with the Part-Task simulation, an interaction of workload and phase of flight should be present in order to demonstrate "selective" discriminability.

Oneway ANOVAs were computed for each flight in order to determine the discriminability of phase of flight. If the oneway ANOVA was found to be significant the Newman-Kuels range statistic was applied to determine which phases of flight were significantly different from one another.

Case-wise deletion still remains an artifact for the repeated measures ANOVA. Any pilot that has missing data in any cell in the analysis is dropped from the ANOVA.

All significant $\underline{F}$ ratios are reported, and the results of the test for a main effect of workload are reported whether there is a statistically significant finding or not.

The same approach will be taken in examining the discriminability of phase of flight by a workload measure as was done in the Part-Task simulation. Utilizing a paired-comparison approach the various phases of flight were compared to one another using the Newman-Kuels range statistic.

9.1.4.2 VALIDITY DECISION CRITERIA

For an assessment technique to demonstrate validity it should find a main effect for workload type. Similar to a main effect of workload, an interaction of workload and phase of flight should be demonstrated to provide evidence of validity or a workload measure.

Similar to the Part-Task simulation, no systematic attempt was made to describe the nature of the Newman-Kuels range statistic due to complications arising from the large number of comparisons. Our approach, simply stated, is the more significant differences that were found the more discriminable the workload measure was thought to be.

9.1.4.3 RELIABILITY ANALYSES

Test/retest was assessed using the same method as the Part-Task simulation. For a given workload measure, each pilot's scores (session 1 and 2) are paired, then a correlation is computed using all the pilot score's for each measurement window. The Nominal and Communication flights will yield seven correlation coefficients each, corresponding to the seven measurement windows. The Malfunction flight will yield eleven correlation coefficients corresponding to the eleven measurement windows.

Similar to the Part-Task simulation, the correlation coefficients for test/retest reliability are based on as many data points as are available. Case-wise deletion is not performed on pilots with missing data.

Inter-rater reliability was assessed in the same fashion as the Part-Task simulation. For a given workload measure, the 25 scores (7 windows from Nominal & Communication and 11 windows the Malfunction flight) for the pilot (average session 1 and 2 scores) are paired with the group mean for the respective measurement windows to yield individual correlation coefficients. Inter-rater reliability is then expressed as a percentage of the pilots that show a significant correlation with the group mean.

9.1.4.4 RELIABILITY DECISION CRITERIA

Similar to the question of reliability criteria brought up in the Part-Task simulation, the exact criterion to determine whether or not a workload measure is reliable can be subject to much debate. When a large number of statistics are computed the Type I error rate is inflated proportional to the number of coefficients computed. Again, a comparison-wise Type I error rate is adopted when examining the correlation coefficients because of the hypotheses advanced (namely that a measure ought to provide the same pattern of results with repeated application).

In the present study it was decided that 20% of the coefficients, 5 out a possible 25, correlations ought to be significant for the workload metric to be considered reliable. There is nothing magical about the 20% figure, nor is any consideration given to the phase of flight or workload conditions (Nominal, Communication, or Malfunction) in which the significant correlations are found.

Another index of reliability is the correlation of each pilot's scores (average test/retest) to the group mean. In order to feel confidence using this index at least half of the subjects should correlate significantly with the group mean.

9.2 RESULTS

9.2.1 SUMMARY OF RESULTS

SWAT, the Bedford scale, Heart Rate (with qualification), and Control Inputs (Wheel, Column, & Pedal) demonstrated evidence of validity by discriminating workload, as well as finding a significant interaction of workload and phase of flight. Heart Rate did not find a significant main effect of workload, although a strong trend did exist for being able to discriminate among the levels of workload.

SWAT, the Bedford scale, Eyeblink, Heart Rate, the Blood Pressure Component of the Power Spectral Analysis and Control Inputs (Wheel, Column, & Pedal) demonstrated evidence of reliability by finding at least five, out of a possible 25, test/retest correlations were significant. The above listed measures also demonstrated inter-rater reliability by at least 50% of the pilots significantly correlated to the group means for the respective workload conditions.

9.2.1.1 SUBJECTIVE RATINGS

SWAT (Post-Flight) and the Bedford scale demonstrated evidence of validity by discriminating among the three different workload flights. SWAT (In-Flight) was not able to discriminate among all three flights. All three measures SWAT (in & Post-Flight) and Bedford all demonstrated evidence of reliability.

<u>SWAT (In-Flight)</u>

To yield the appropriate 0 to 100 scaling solution for the SWAT ratings, the prototype solutions for the appropriate subjects. The Kendall's coefficient of concordance (0.7256) for the individual's card sorts was less than the recommended .78 for using the group scaling solution, so prototype solutions were used instead. Two primary dimensions were found from the prototype analysis: Stress and Time. One subject was found to have an Effort prototype, but was switched to the next greatest prototype tendency, namely Stress. Of the 16 subjects in the analysis, 9 found Stress to be the most important dimension in the card sort, while the remaining 7 found Time to be the most important dimension.

SWAT (In-Flight) could not discriminate among the three workload flights, $\underline{F} < 1$, although a significant workload by phase of flight interaction was found, $\underline{F}(12,168)=5.11$, ($MSe=192$, $\underline{p}<.01$) (Figures 9.2.1.1-1 to 9.2.1.1-4 and Table 9.2.1.1-1).

A comparison of the Nominal-Malfunction flights found a significant interaction of workload by phase of flight, $\underline{F}(6,84)=6.49$, ($MSe=206$, $\underline{p}<.01$). A comparison of the Communication-Malfunction flights found a significant interaction of workload by phase of flight, $\underline{F}(6,84)=7.32$, ($MSe=191$, $\underline{p}<.01$).

A main effect for the phase of flight comparison was found for all three types of workload flights, $\underline{F}(6,84)=25.59$, ($MSe=344$, $\underline{p}<.01$). A oneway ANOVA found a main effect for phase of flight significant for the Nominal workload flight, $\underline{F}(6,90)=10.98$, ($MSe=129$, $\underline{p}<.01$). A Newman-Kuels range statistic was computed to determine SWAT's ability to discriminate various phases of flight from one another in the Nominal workload flight, 9

Figure 9.2.1.1-1

In-Flight SWAT

Full Mission Simulation

Nominal Flight SFO - SCK

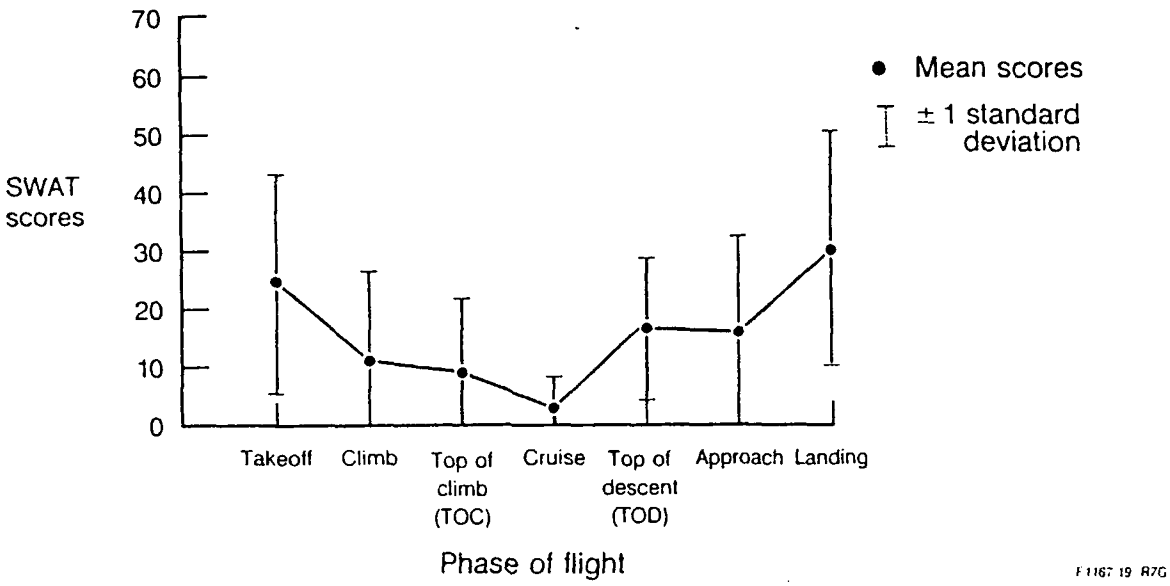


Figure 9.2.1.1-2

In-Flight SWAT

Full Mission Simulation

Communications Fligh' SMF - SFO

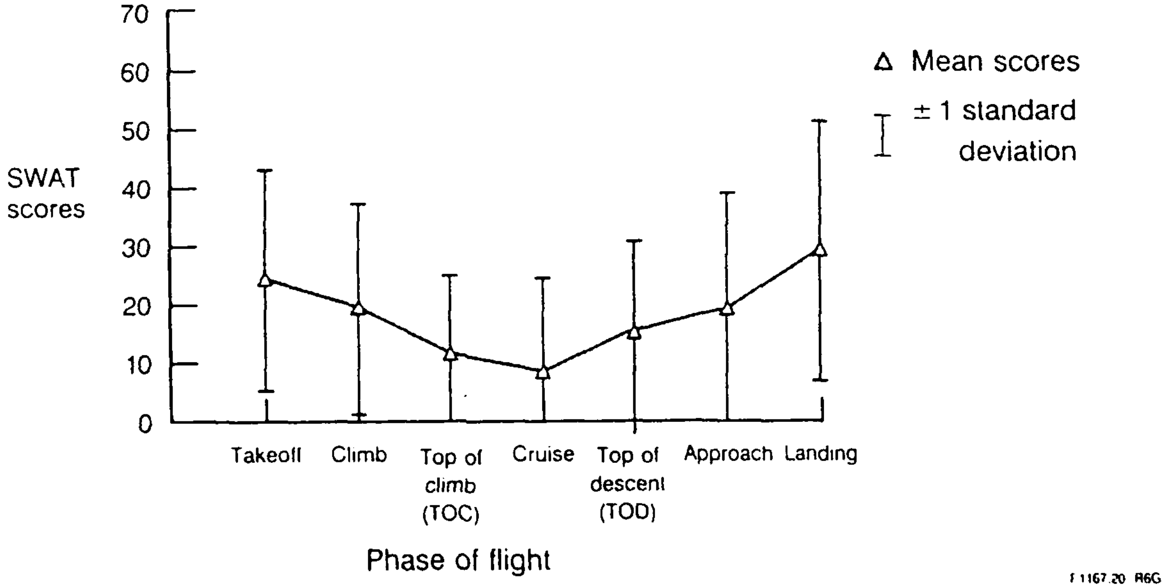


Figure 9.2.1.1-3

In-Flight SWAT

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

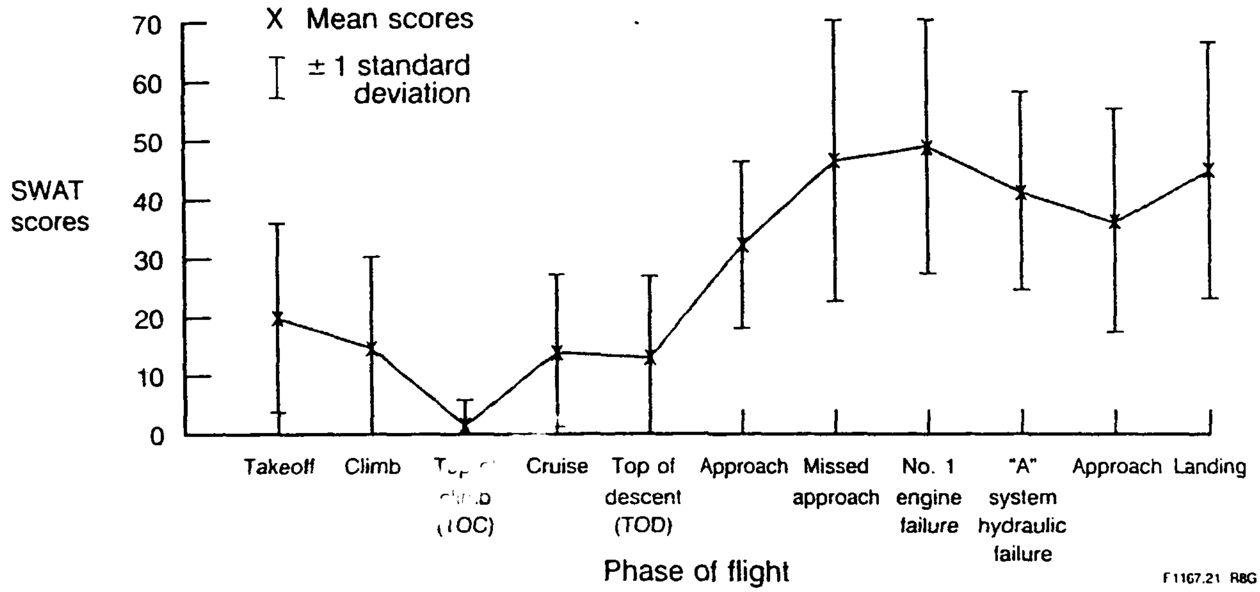


Figure 9.2.1.1-4

In-Flight SWAT

Full Mission Simulation

All Flights

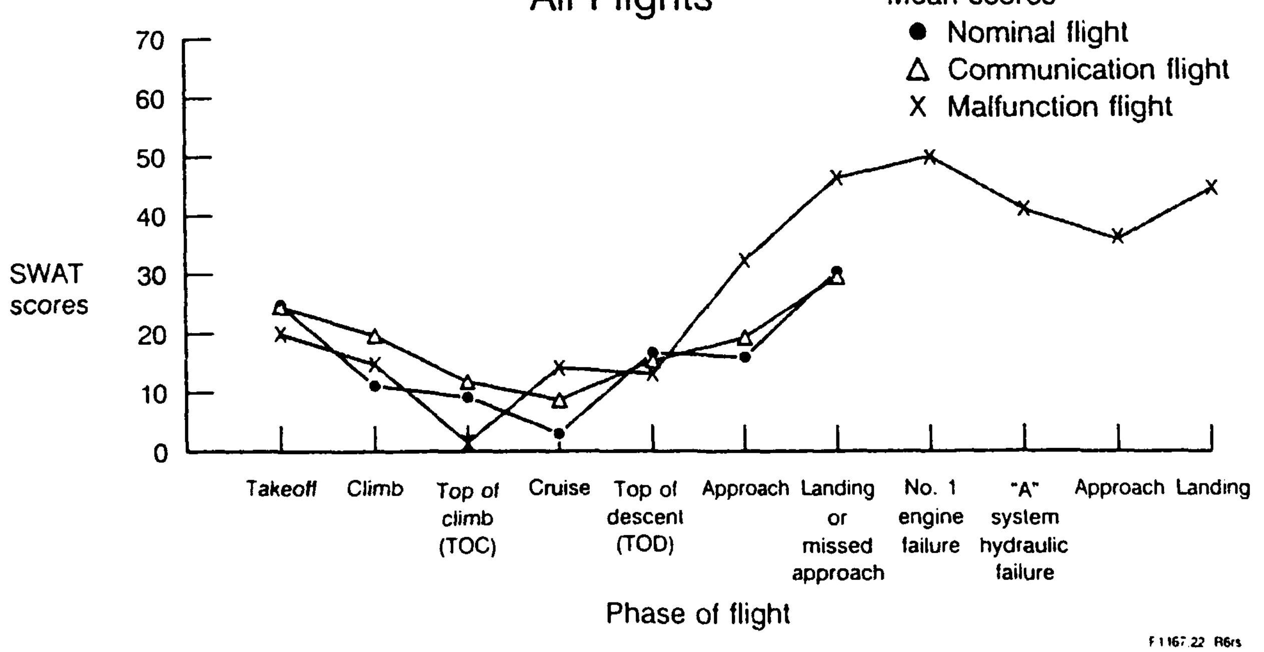


Table 9.2.1.1-1

Subjective Workload Assessment Technique (In-Flight SWAT)

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	24.8	(19.8)	24.5	(18.9)	20.0	(16.1)
Climb	11.1	(15.6)	19.6	(18.0)	14.7	(15.2)
Top of climb	9.1	(12.8)	11.7	(13.5)	1.4	(3.9)
Cruise	2.9	(5.5)	8.6	(16.2)	14.1	(13.0)
Top of descent	16.6	(12.2)	15.2	(18.0)	13.1	(13.8)
Approach	15.9	(16.6)	19.3	(20.1)	32.2	(14.2)
Landing or M/A	30.4	(20.1)	29.4	(22.2)	46.4	(23.9)
No. 1 engine failure					48.8	(21.5)
"A" hydraulic failure					41.2	(16.9)
Approach					36.0	(18.9)
Landing					44.6	(21.5)

H1167.04 R2dD

Table 9.2.1.1-2

SWAT (In-Flight)

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.50	0.44	0.68*
Climb	0.82*	0.36	0.74*
Top of climb	0.50	0.39	-0.07
Cruise	0.05	0.72*	0.40
Top of descent	0.52	0.78*	0.46
Approach	0.60	0.76*	0.48
Landing or missed approach	0.49	0.58	r(13) = 0.79*
No. 1 engine failure			r(13) = 0.40
"A" system hydraulics failure			0.60
Approach			0.53
Landing			r(13) = 0.63

r(14) = 0.623*
* Significant p < 0.01

F1167.13 R9rA

out of 21 comparisons were significant. A oneway ANOVA found a main effect for phase of flight significant for the Communication workload flight, $F(6,90)=9.89$, ($MSe=84$, $p<.01$). The ability to discriminate phase of flight conditions for the Communication flight found 6 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight significant for the Malfunction workload flight, $F(10,130)=22.47$, ($MSe=166$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 30 out of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.1-2). For the nominal flight there was one significant correlation out of a possible seven. For the communication and malfunction flights there were 3 out of 7, and 3 out of 11, significant correlations, respectively.

In assessing inter-rater reliability, it was found that 94% of the subjects scores were significantly correlated with means for the 25 measurement windows.

SWAT (Post-Flight)

The same scaling solution was used for determining the 0-to-100 workload for the In-Flight event ratings was used for the Post-Flight event ratings. The same, pre-flight, card sort determined the prototype solutions for the two groups: Time and Stress.

SWAT (Post-Flight) found a main effect among the three workload flights, $F(2,28)=17.21$, ($MSe=252$, $p<.01$). In addition, a significant workload by phase of flight interaction was found $F(12,168)=11.52$, ($MSe=206$, $p<.01$) (Figures 9.2.1.1-5 to 9.2.1.1-8 and Table 9.2.1.1-3).

A comparison of the Nominal-Malfunction flights found a significant main effect of workload and an interaction of workload by phase of flight, $F(1,14)=26.50$, ($MSe=310$, $p<.01$) and $F(6,84)=13.32$, ($MSe=271$, $p<.01$), respectively. A comparison of the Communication-Malfunction flights found a significant main effect of workload and an interaction of workload by phase of flight, $F(1,14)=13.13$, ($MSe=218$, $p<.01$) and $F(6,84)=12.68$, ($MSe=247$, $p<.01$), respectively.

A main effect for phase of flight comparison was found for all three types of workload flights, $F(6,84)=25.81$, ($MSe=375$, $p<.01$). A oneway ANOVA found a main effect for phase of flight significant for the Nominal workload flight, $F(6,90)=11.52$, ($MSe=129$, $p<.01$). A Newman-Kuels range statistic was computed to determine SWAT's ability to discriminate various phases of flight from one another in the Nominal workload flight 7 out of 21 comparisons were significant. A oneway ANOVA found a main effect for phase of flight significant for the Communication workload flight, $F(6,90)=7.24$, ($MSe=121$, $p<.01$). The ability to discriminate phase of flight conditions for the Communication flight found 7 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight was significant for the Malfunction workload flight, $F(10,130)=28.32$, ($MSe=192$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 33 out of 55 comparisons significant.

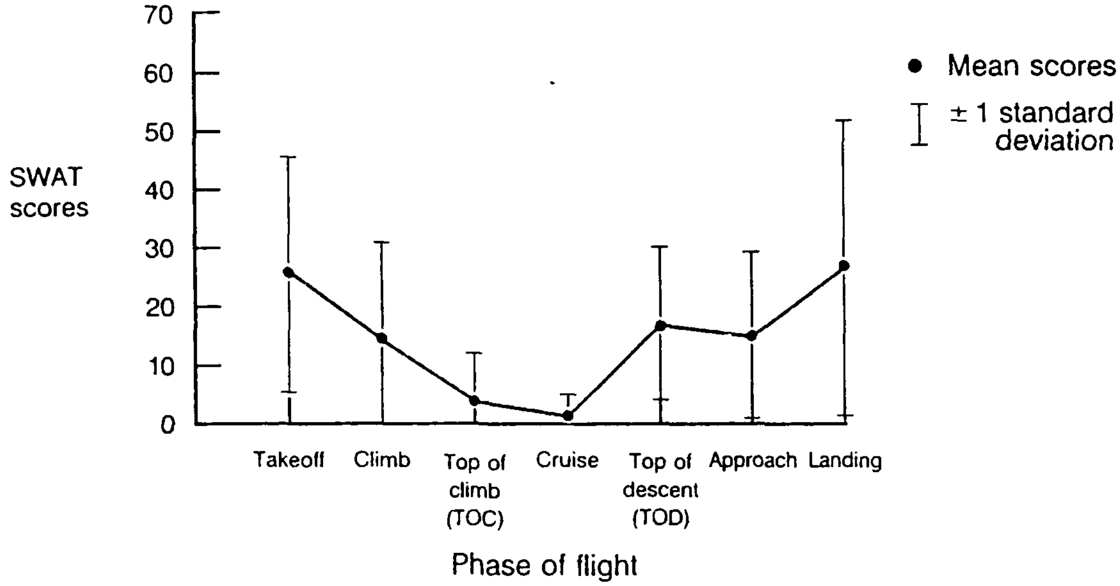
Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.1-4). For the nominal flight there were two significant correlations out of a possible seven. For the communication and malfunction flights there were 3 out 7, and 5 out of 11, significant correlations, respectively.

Figure 9.2.1.1-5

Post-Flight SWAT

Full Mission Simulation

Nominal Flight SFO - SCK



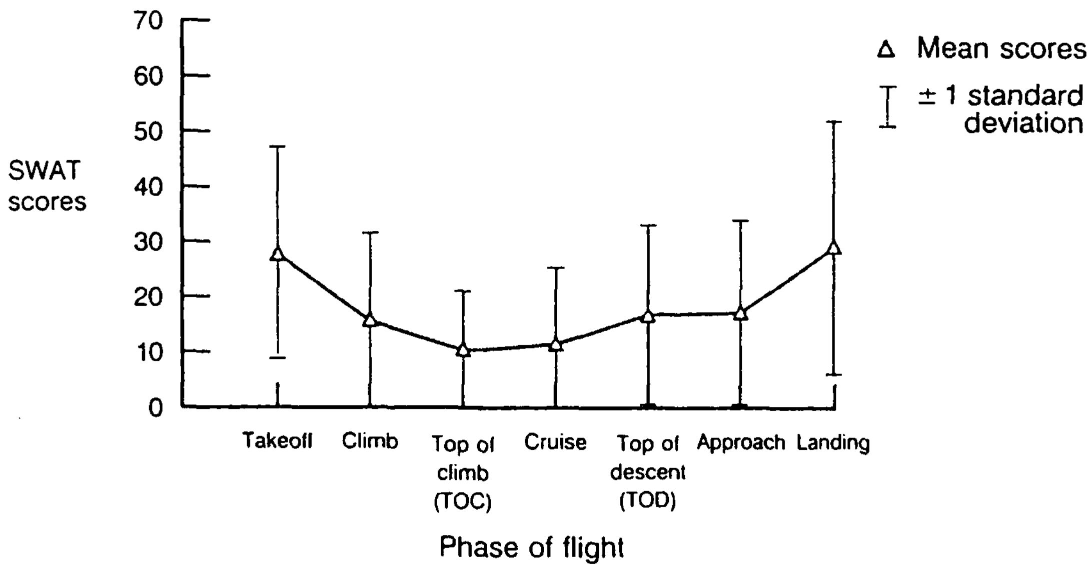
F1167.27 R5G

Figure 9.2.1.1-6

Post-Flight SWAT

Full Mission Simulation

Communications Flight SMF - SFO



F1167.28 R4rs

Figure 9.2.1.1-7

Post-Flight SWAT

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

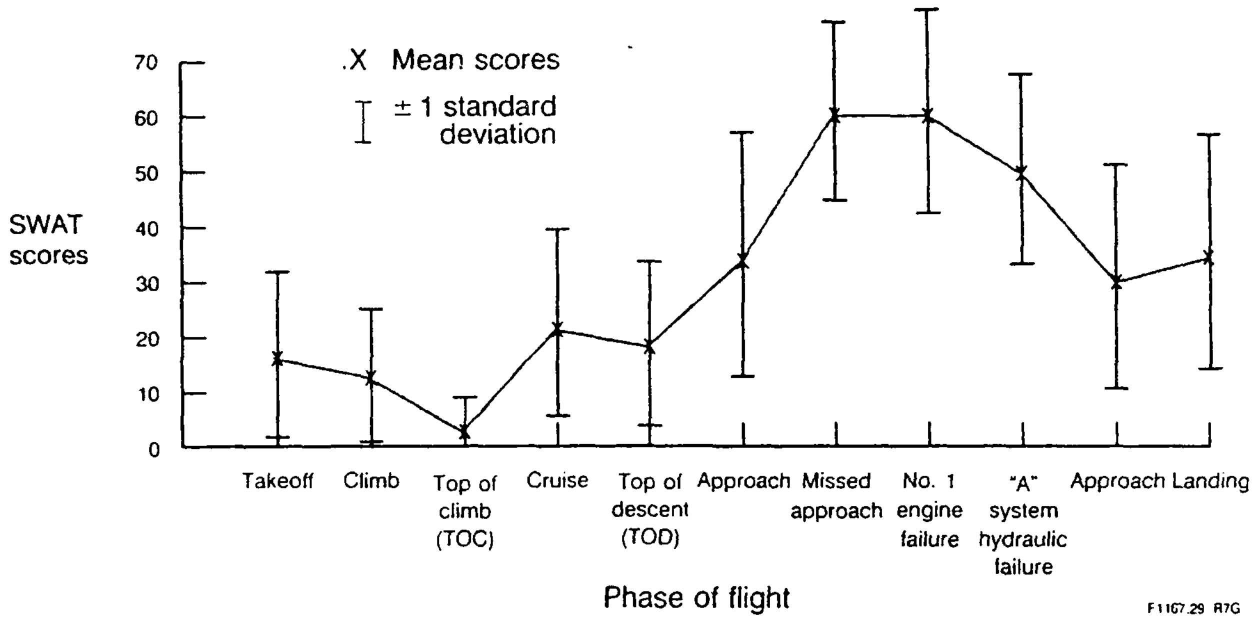


Figure 9.2.1.1-8

Post-Flight SWAT

Full Mission Simulation

All Flights

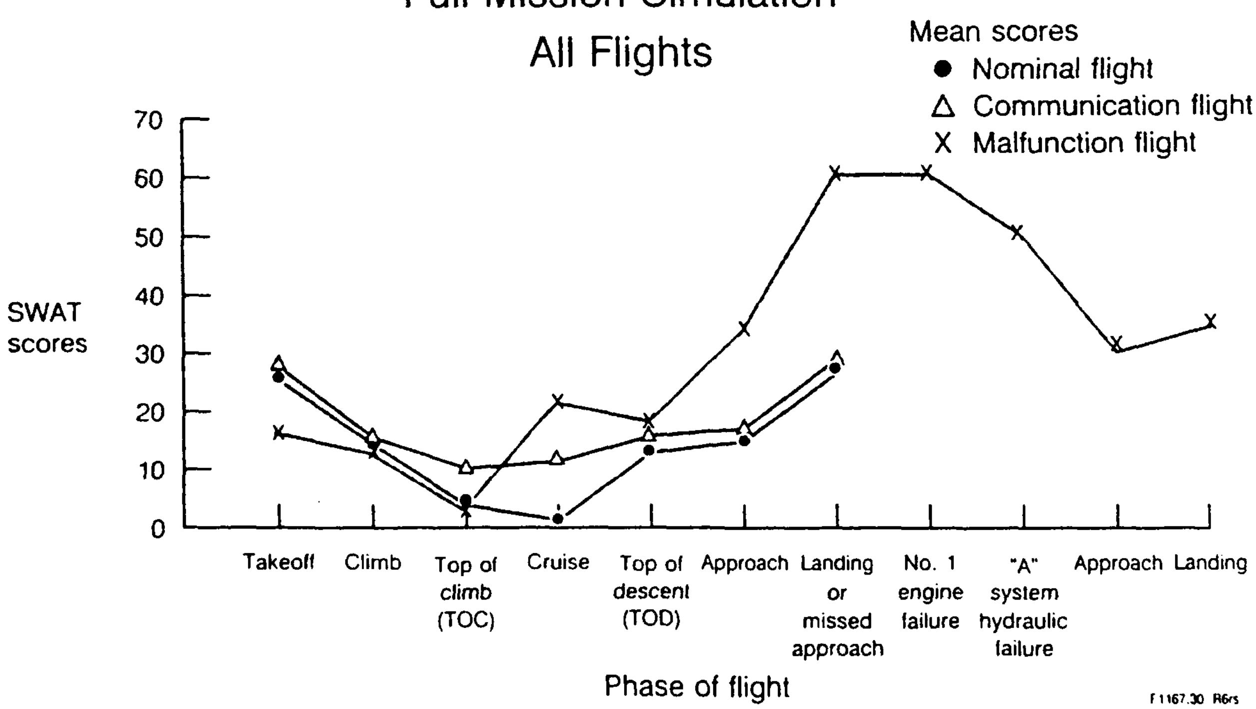


Table 9.2.1.1-3

Subjective Workload Assessment Technique (Post-Flight SWAT)

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	25.6	(20.2)	27.8	(19.3)	16.3	(15.9)
Climb	14.4	(16.3)	15.6	(16.3)	12.7	(12.8)
Top of climb	3.9	(7.7)	10.2	(10.8)	2.9	(6.5)
Cruise	1.3	(13.1)	11.4	(14.3)	21.3	(17.5)
Top of descent	16.9	(13.1)	16.8	(15.9)	18.2	(15.8)
Approach	14.9	(14.2)	17.1	(17.0)	33.7	(23.5)
Landing or M/A	26.5	(25.0)	29.0	(22.8)	59.9	(17.2)
No. 1 engine failure					59.8	(19.6)
"A" hydraulic failure					49.4	(18.2)
Approach					29.8	(21.5)
Landing					34.2	(22.5)

H1167 05 R2db

Table 9.2.1.1-4

SWAT (Post-Flight)

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.74*	0.44	0.42
Climb	0.59	0.82*	0.41
Top of climb	0.43	-0.05	0.71*
Cruise	-0.08	0.31	0.66*
Top of descent	0.15	0.65*	0.29
Approach	0.39	0.60	0.66*
Landing or missed approach	0.81*	0.66*	r(13) = 0.75*
No. 1 engine failure			0.44
"A" system hydraulics failure			0.53
Approach			0.55
Landing			0.69*

r(14) = 0.623*
* Significant $p < 0.01$

F1167 12 R9rk

In assessing inter-rater reliability, it was found that 94% of the subjects scores were significantly correlated with means for the 25 measurement windows.

BEDFORD RATING

No transformation, from event rating to workload score, is necessary for the Bedford rating. Pilots made ratings, from 1-to-10, low to high, with half ratings (i.e., 3 1/2) allowed.

Bedford ratings found a main effect for workload, $F(2,28)=12.55$, ($MSe=1$, $p<.01$). In addition, a significant workload flight by phase of flight interaction was found, $F(12,168)=10.57$, ($MSe=0.57$, $p<.01$) (Figures 9.2.1.1-9 to 9.2.1.1-12 and Table 9.2.1.1-5).

A comparison of the Nominal-Communication flights found a significant main effect of workload type, $F(1,15)=8.84$, ($MSe=0.75$, $p<.01$). A comparison of the Nominal-Malfunction flights found a main effect of workload and an interaction of workload by phase of flight, $F(1,14)=17.96$, ($MSe=1.4$, $p<.01$) and $F(6,64)=18.60$, ($MSe=0.5$, $p<.01$). A comparison of the Communication-Malfunction flights found a significant main effect of workload and an interaction of workload by phase of flight, $F(1,14)=8.71$, ($MSe=0.86$, $p<.01$) and $F(6,84)=10.99$, ($MSe=0.75$, $p<.01$), respectively.

A main effect for phase of flight discrimination was found, $F(6,84)=27.78$, ($MSe=0.98$, $p<.01$). A oneway ANOVA found a main effect for phase of flight discrimination for the Nominal workload flight, $F(6,90)=15.82$, ($MSe=0.16$, $p<.01$). A Newman-Kuels range statistic was computed to determine the ability of the Bedford ratings to discriminate various phases of flight from one another in the Nominal workload flight, 11 out of 21 comparisons were significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Communication workload flight, $F(6,90)=5.82$, ($MSe=0.37$, $p<.01$). The ability to discriminate phase of flight conditions for the Communication flight found 6 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,130)=25.58$, ($MSe=0.59$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 35 out of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.1-6). For the Nominal flight there were two significant correlation out of a possible seven. For the Communication and Malfunction flights there were 1 out 7, and 1 out of 11, significant correlations, respectively.

In assessing inter-rater reliability, it was found that 94% of the subjects scores were significantly correlated with means for the 25 measurement windows.

9.2.1.2 PHYSIOLOGICAL MEASURES

Eyeblink rate and heart rate, measured by inter-beat interval, both demonstrate evidence of validity by discriminating between the different types of workload. Eyeblinks, heart rate, and the blood pressure component of the power spectral analysis all demonstrate evidence for test/retest and inter-rater reliability.

EYEBLINK

Using the same scoring protocol as the Part-Task simulation, a strip chart printout of the vertical electro-occulogram analog signal was analyzed for eyeblinks. The number of eyeblinks per minute was then computed to determine eyeblink rate.

Figure 9.2.1.1-9

Bedford Rating

Full Mission Simulation

Nominal Flight SFO - SCK

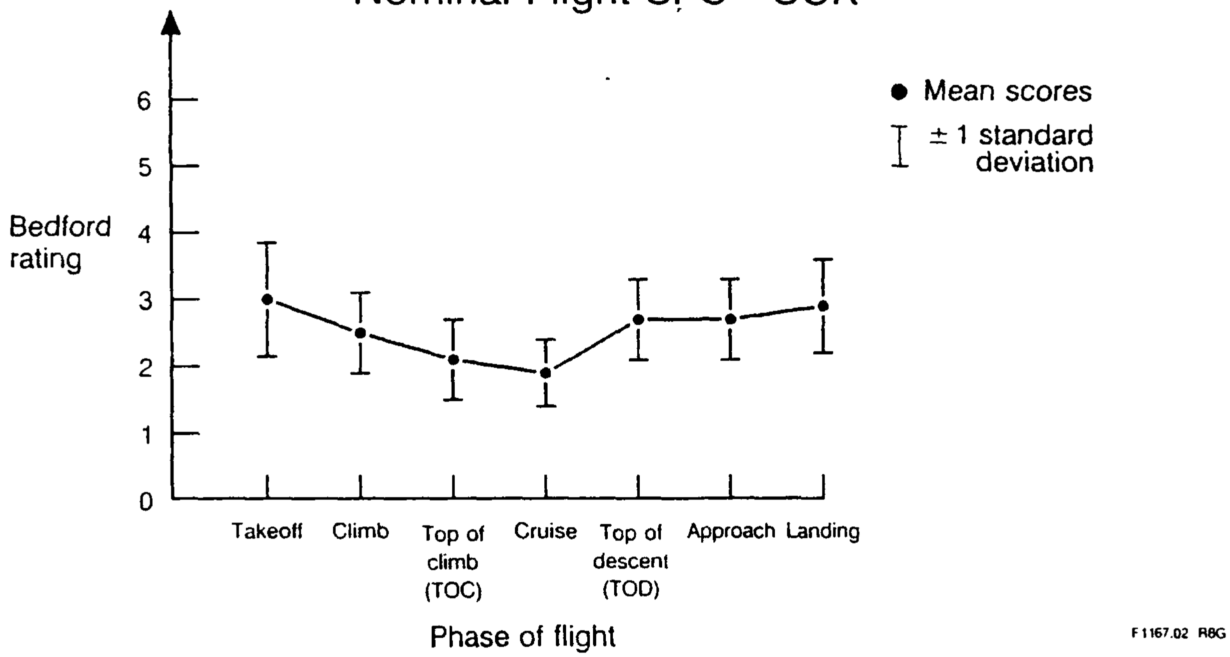


Figure 9.2.1.1-10

Bedford Rating

Full Mission Simulation

Communication Flight SMF - SFO

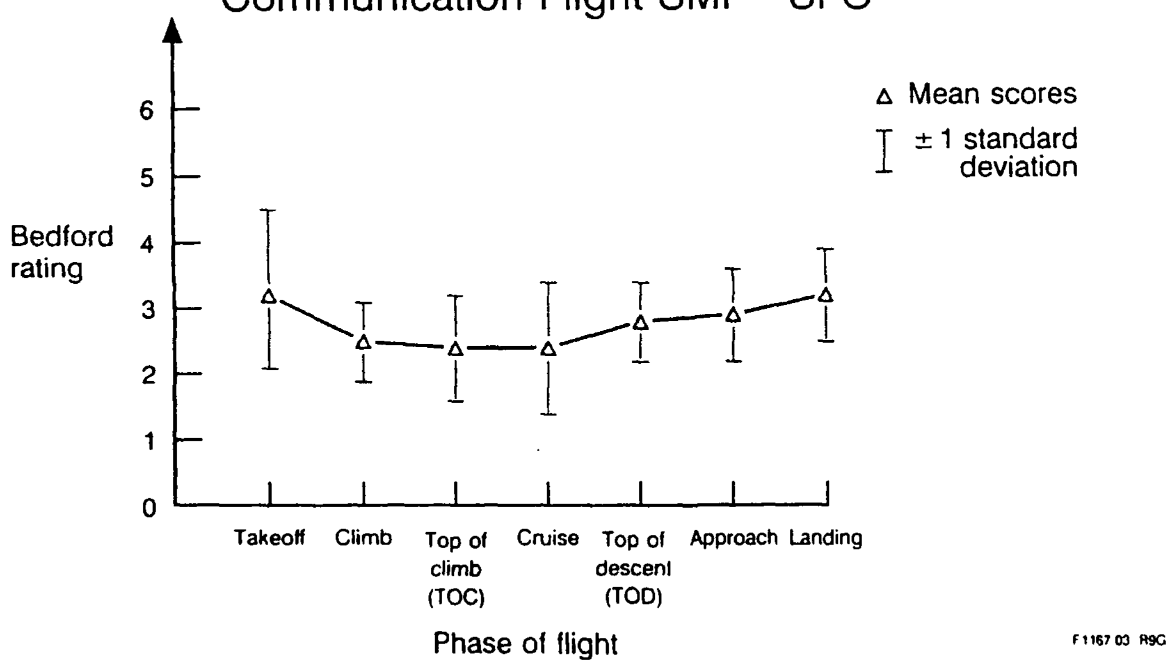


Figure 9.2.1.1-11

Bedford Rating

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

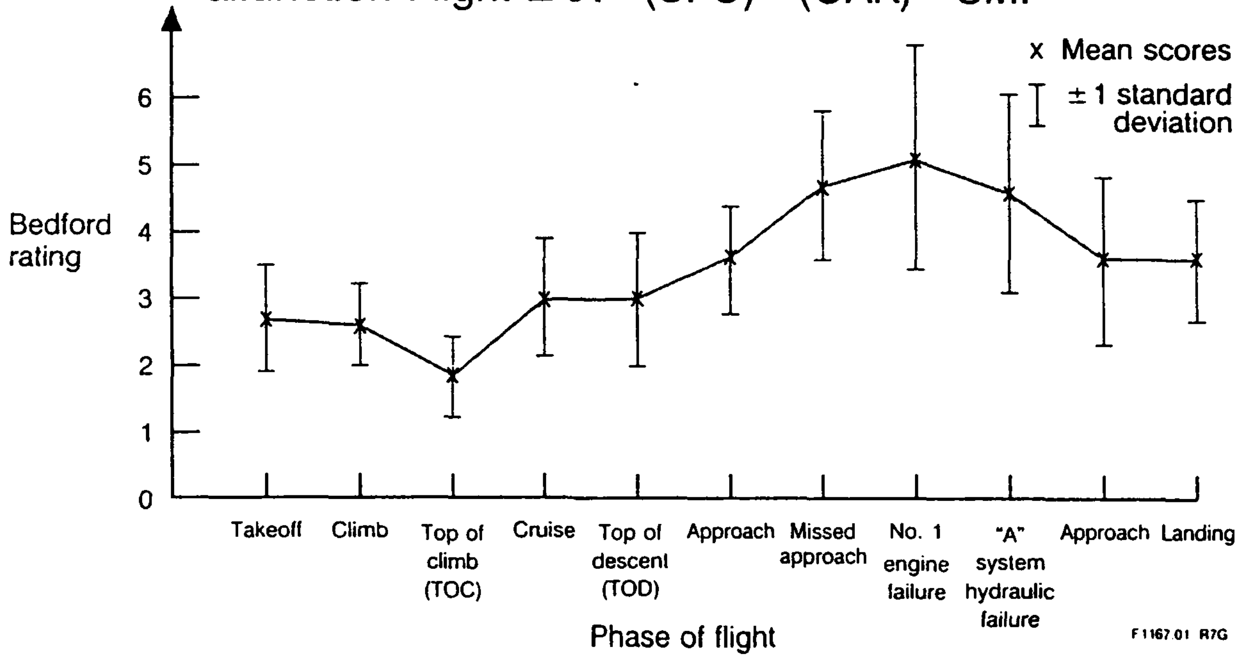


Figure 9.2.1.1-12

Bedford Rating

Full Mission Simulation

All Flights

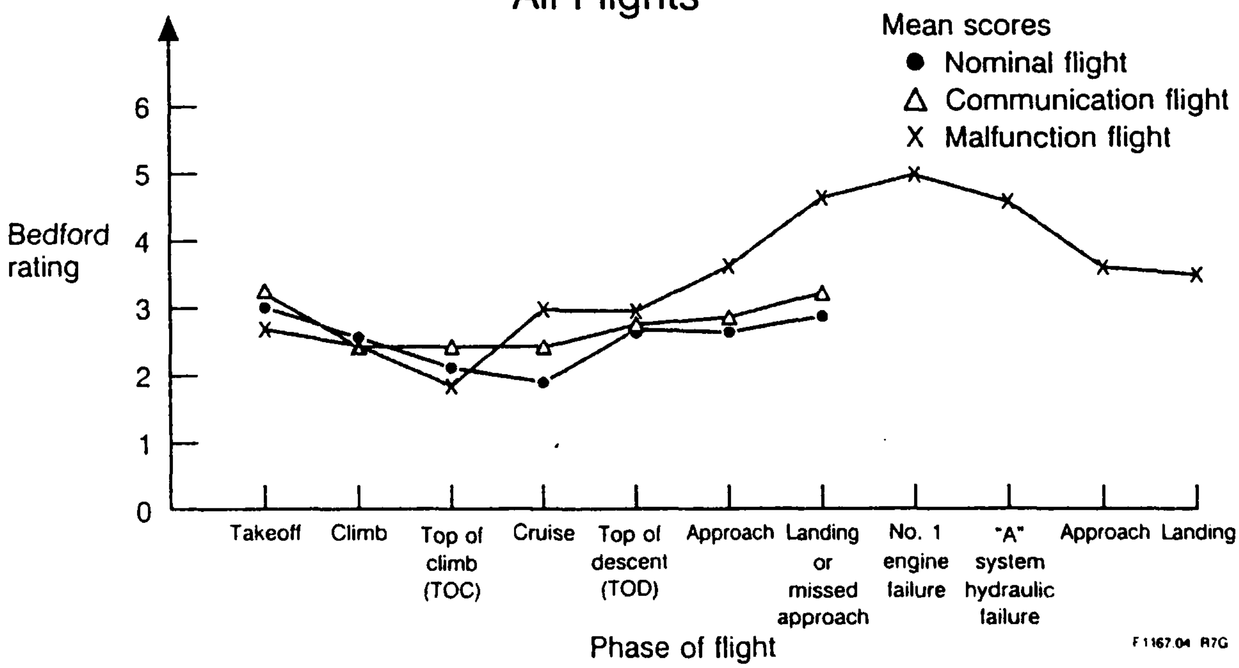


Table 9.2.1.1-5

Bedford Ratings

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	3.0	(0.85)	3.3	(1.18)	2.7	(0.76)
Climb	2.5	(0.58)	2.5	(0.59)	2.6	(0.62)
Top of climb	2.1	(0.56)	2.4	(0.80)	1.8	(0.59)
Cruise	1.9	(0.55)	2.4	(0.99)	3.0	(0.85)
Top oi descent	2.7	(0.56)	2.8	(0.60)	3.0	(0.99)
Approach	2.7	(0.62)	2.9	(0.72)	3.6	(0.83)
Landing or M/A	2.9	(0.72)	3.2	(0.74)	4.7	(1.10)
No. 1 engine failure					5.1	(1.65)
"A" hydraulic failure					4.6	(1.46)
Approach					3.6	(1.26)
Landing					3.6	(0.86)

H1167 06 R3cD

Table 9.2.1.1-6

Bedford Rating

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.45	0.64*	0.61
Climb	0.64*	0.51	0.31
Top of climb	0.40	0.01	0.18
Cruise	0.26	0.15	0.59
Top of descent	0.17	0.42	0.55
Approach	0.58	0.44	0.29
Landing or missed approach	0.66*	0.04	r(13) = 0.16
No. 1 engine failure			0.63*
"A" system hydraulics failure			0.50
Approach			0.62
Landing			r(13) = 0.26

r(14) = 0.623*
* Significant p < 0.01

F1167 14 R8G

Blink rate found a strong trend for a main effect among the three workload flights, $F(2,28) = 5.59$, ($MSe = 33$, $p < .012$). In addition, a workload by phase of flight interaction was found, $F(12,120) = 4.59$, ($MSe = 21$, $p < .01$) (Figures 9.2.1.2-1 to 9.2.1.2-4 and Table 9.2.1.2-1).

A comparison of the Nominal-Malfunction flights found a interaction of workload by phase of flight, $F(6,60) = 7.10$, ($MSe = 19$, $p < .01$). A comparison of the Communication-Malfunction flights found a main effect of workload and an interaction of workload by phase of flight, $F(1,10) = 10.63$, ($MSe = 34$, $p < .01$) and $F(6,60) = 5.82$, ($MSe = 20$, $p < .01$), respectively.

A main effect for phase of flight discrimination was found, $F(6,84) = 5.21$, ($MSe = 39$, $p < .01$). A oneway ANOVA found a strong trend for a main effect for phase of flight discrimination for the Communication workload flight, $F(6,60) = 2.44$, ($MSe = 11$, $p < .04$). There was no ability to discriminate phase of flight conditions for the Communication flight. A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,100) = 6.36$, ($MSe = 22$, $p < .01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 11 out of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.2-2). For the Nominal flight there were four significant correlations out of a possible seven. For the Communication and Malfunction flights there were 4 out 7, and 6 out of 11, significant correlations, respectively.

In assessing inter-rater reliability, it was found that 73% of the subjects scores were significantly correlated with means for the 25 measurement windows.

HEART RATE (INTER-BEAT INTERVAL)

Heart rate was calculated using the same method as the Part-Task simulation, the R-R interbeat interval.

Inter-beat interval showed a strong trend for a main effect for discriminating among the three workload flights, $F(2,28) = 2.98$, ($MSe = 9024$, $p < .07$). In addition, a significant workload by phase of flight interaction was found, $F(12,168) = 4.03$, ($MSe = 465$, $p < .01$) (Figures 9.2.1.2-5 to 9.2.1.2-8 and Table 9.2.1.2-3).

In addition, as was found for the Part-Task simulation, a strong trend for a main effect of session (day 1 faster than day 2) $F(1,14) = 8.30$, ($MSe = 56079$, $p < .01$). The slowing of the heart rate is thought to reflect a "learning effect" from the test to the retest portion of the study. A comparison of the Nominal-Communication flights found a main effect of session (day 1 faster than day 2), $F(1,14) = 10.03$, ($MSe = 37251$, $p < .01$). Strong trends for session main effects were found for separate comparisons of the Nominal-Malfunction and Communication-Malfunction flights, $F(1,14) = 6.87$, ($MSe = 38558$, $p < .02$) and $F(1,14) = 7.88$, ($MSe = 37779$, $p < .01$), respectively.

A comparison of the Nominal-Malfunction flights found a strong trend for a main effect of workload and an interaction of workload by phase of flight, $F(1,14) = 5.83$, ($MSe = 6126$, $p < .03$) and $F(6,84) = 4.38$, ($MSe = 527$, $p < .01$), respectively. A comparison of the Communication-Malfunction flights found a strong trend for a main effect of workload and an interaction of workload by phase of flight, $F(1,14) = 4.16$, ($MSe = 10609$, $p < .06$) and $F(6,84) = 6.34$, ($MSe = 394$, $p < .01$), respectively.

Figure 9.2.1.2-1

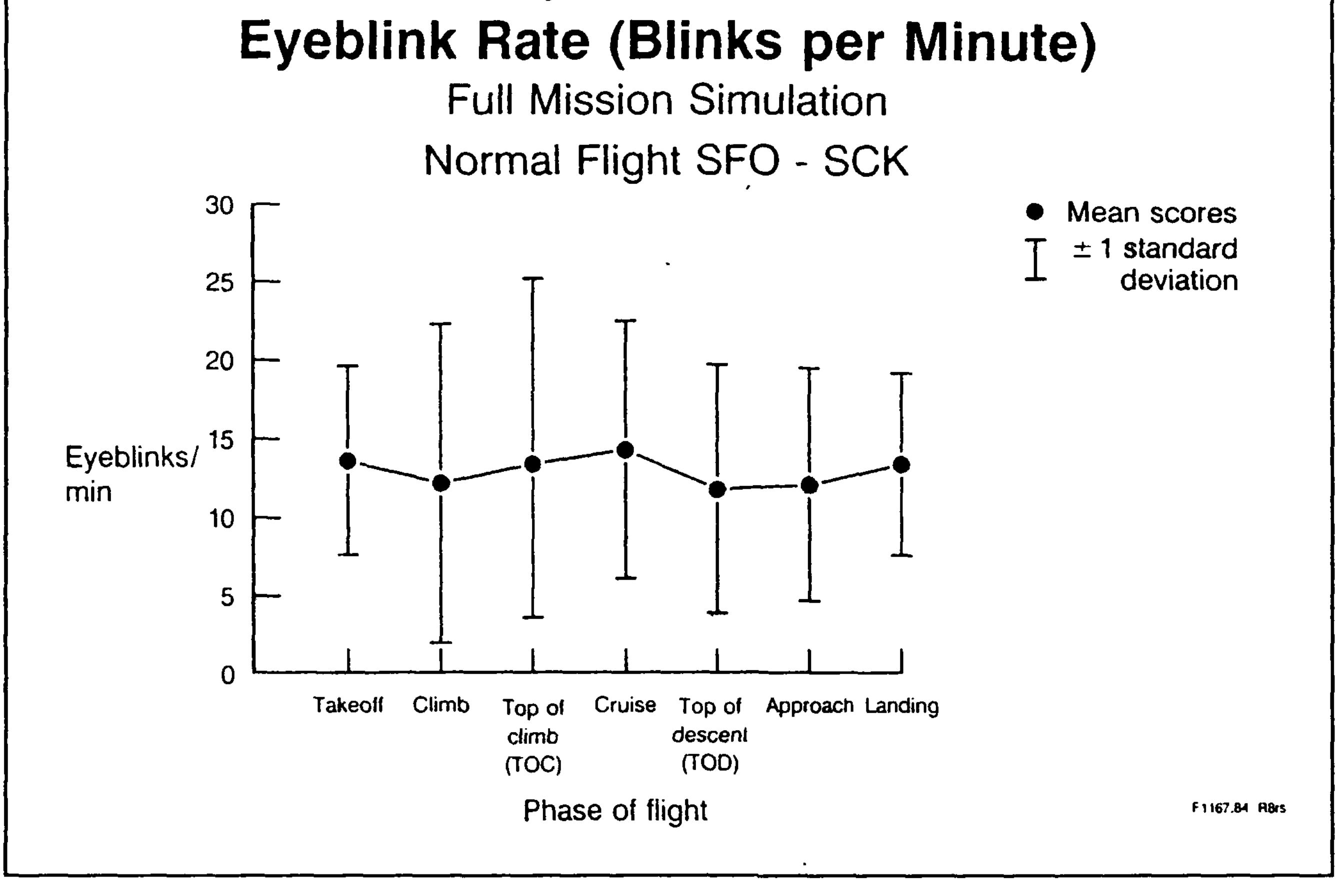


Figure 9.2.1.2-2

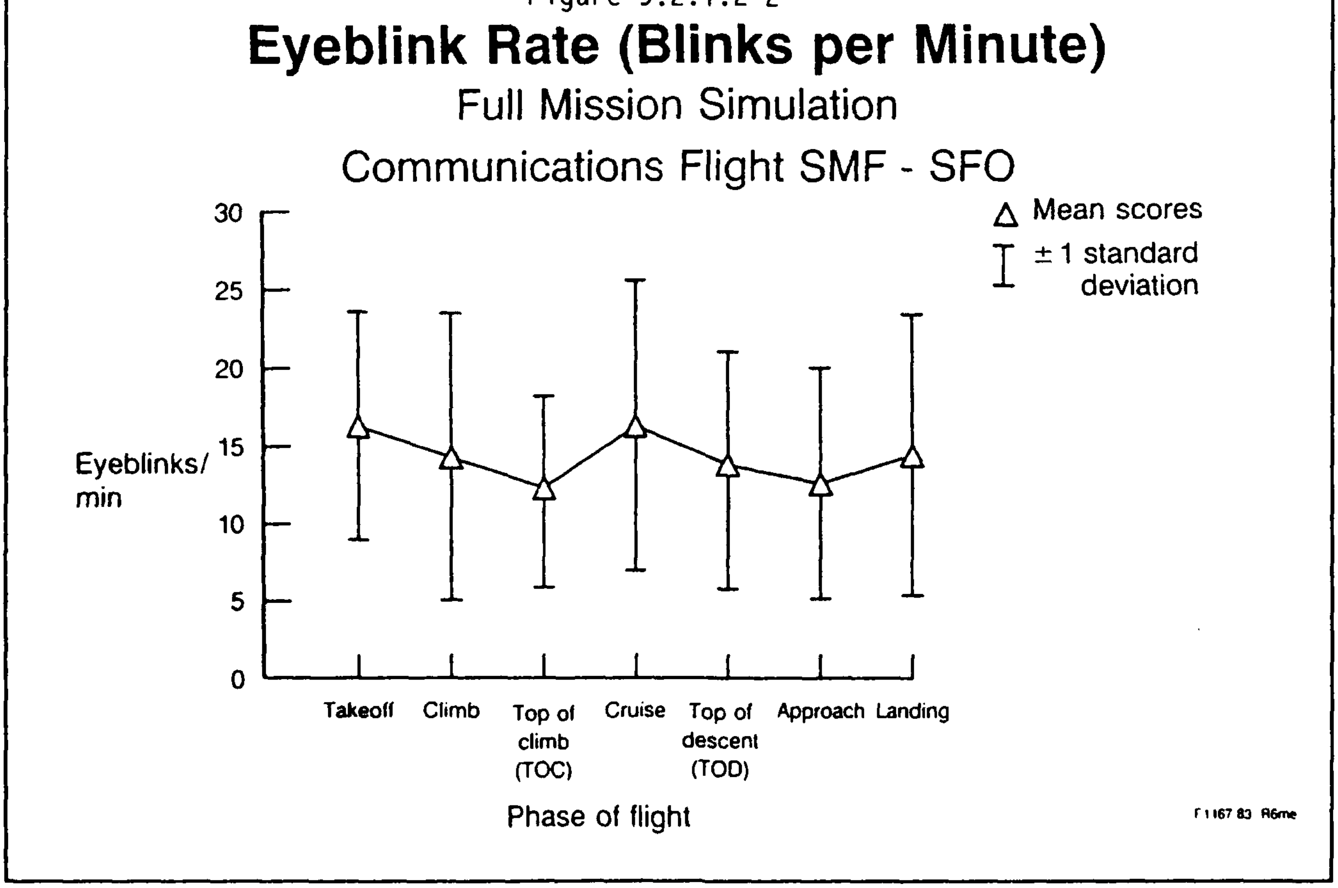


Figure 9.2.1.2-3

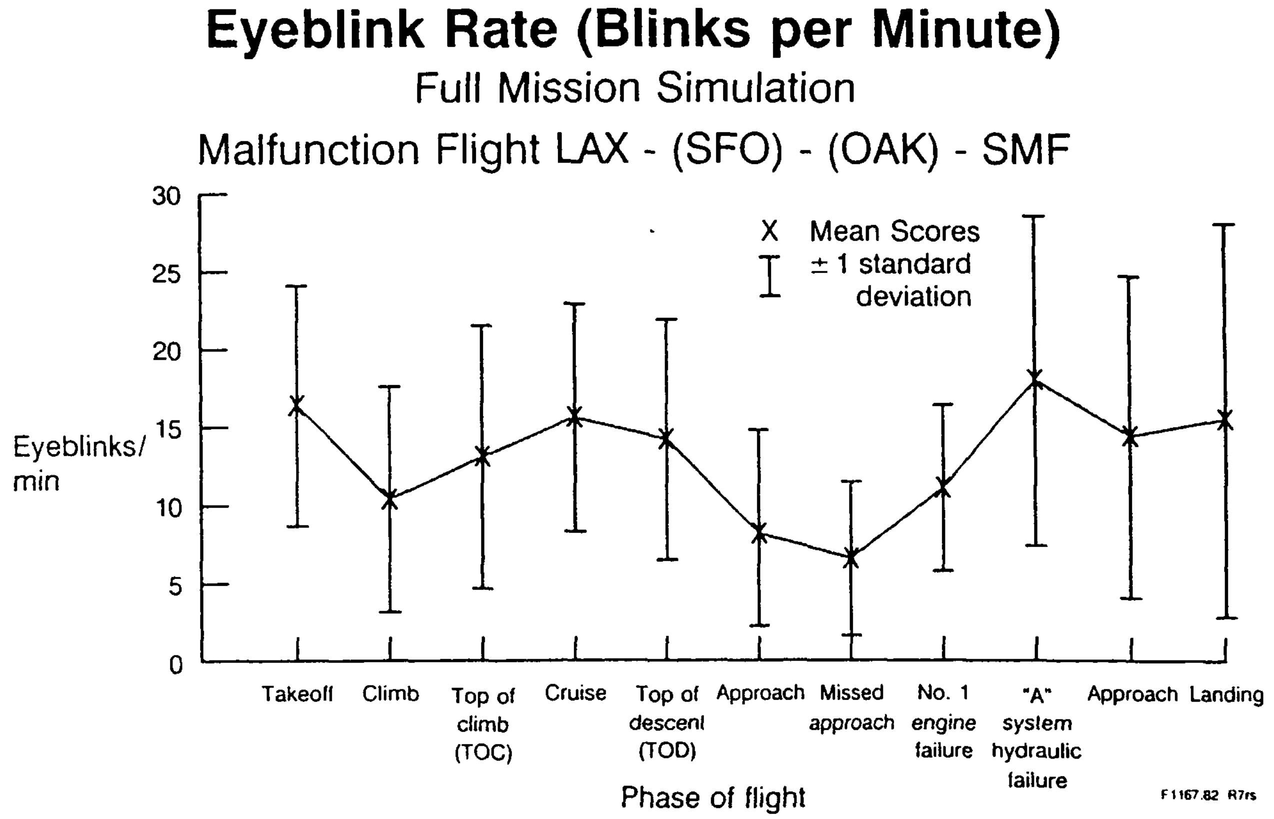


Figure 9.2.1.2-4

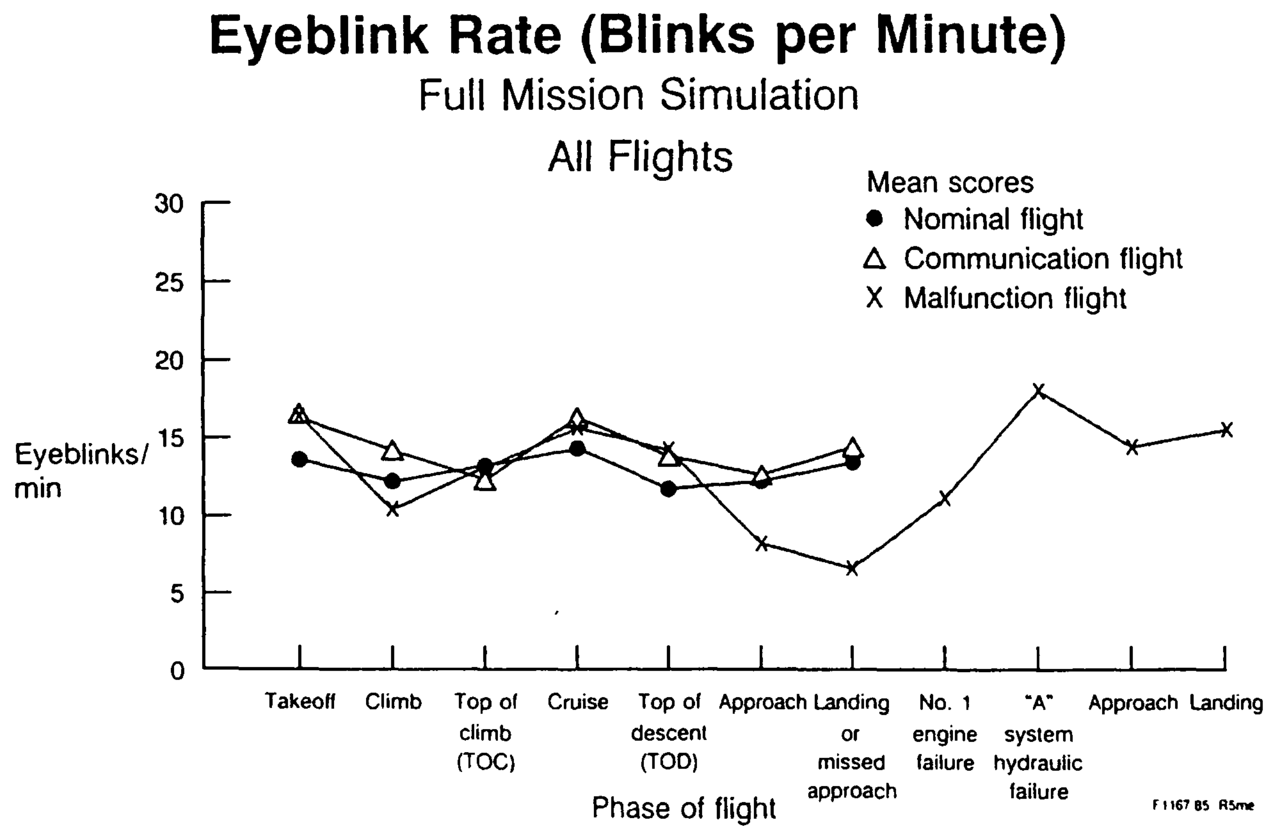


Table 9.2.1.2-1

Eyeblink Rate (Blinks per Minute)

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	13.6	(6.0)	16.3	(7.3)	16.4	(7.7)
Climb	12.2	(10.2)	14.3	(9.2)	10.4	(7.2)
Top of climb	13.4	(9.8)	12.3	(6.4)	13.2	(8.4)
Cruise	14.3	(8.2)	16.3	(9.3)	15.6	(7.3)
Top of descent	11.8	(7.9)	13.8	(8.0)	14.2	(7.7)
Approach	12.2	(7.4)	12.6	(7.4)	8.3	(5.9)
Landing or M/A	13.4	(5.8)	14.4	(9.0)	6.6	(4 9)
No. 1 engine failure					11.2	(5.3)
"A" hydraulic failure					18.0	(10.6)
Approach					14.4	(10.3)
Landing					15.5	(12.6)

H1167 07 R4db

Table 9.2.1.2-2

Eyeblink Rate

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.74*	0.82*	0.78*
Climb	0.73	0.62	0.96*
Top of climb	0.91*	0.71	0.77*
Cruise	0.94*	0.82*	0.62
Top of descent	0.88*	0.90*	0.78*
Approach	0.01	0.83*	0.94*
Landing or missed approach	0.31	0.59	0.62
No. 1 engine failure			0.52
"A" system hydraulics failure			0.77*
Approach			0.41
Landing			0.29

r(9) = .735*
*Significant p .01

Figure 9.2.1.2-5

Inter-Beat Interval (Msec)

Full Mission Simulation

Nominal Flight SFO - SCK

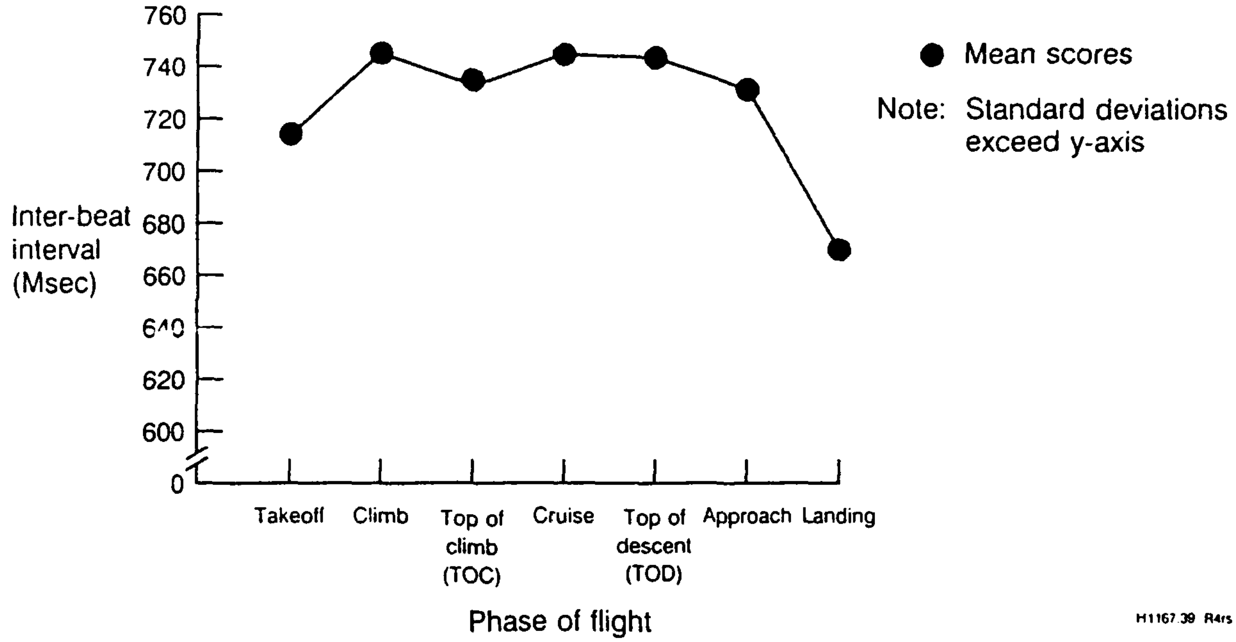


Figure 9.2.1.2-6

Inter-Beat Interval (Msec)

Full Mission Simulation

Communication Flight SMF - SFO

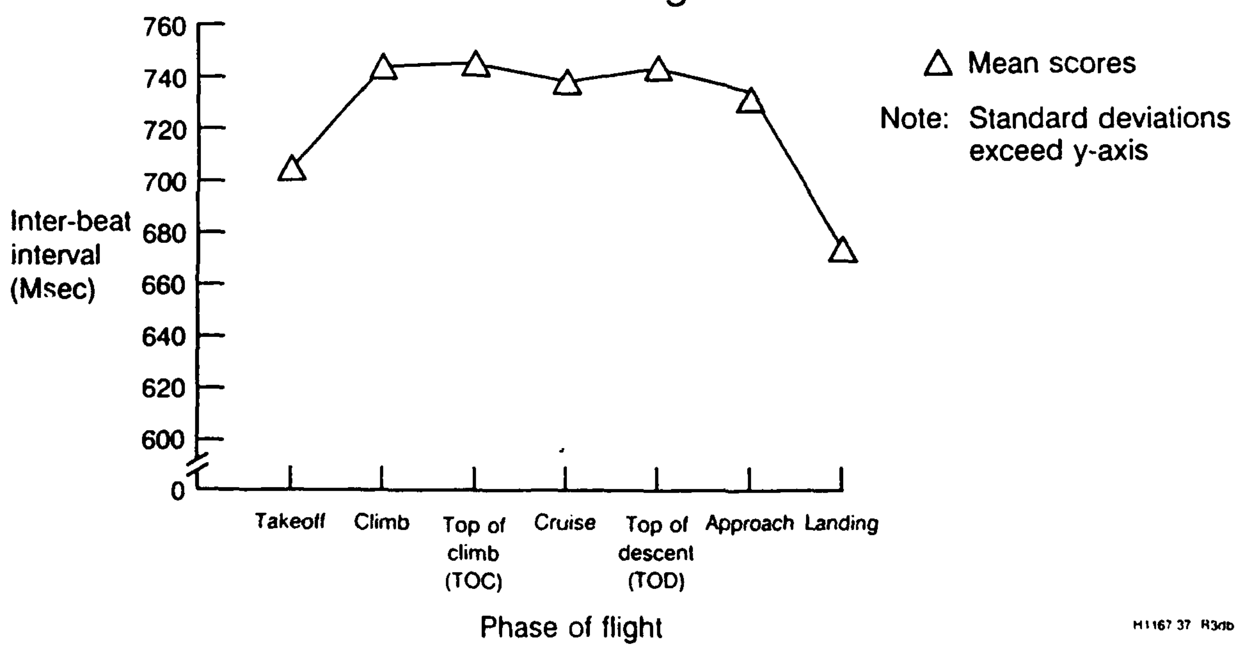


Figure 9.2.1.2-7

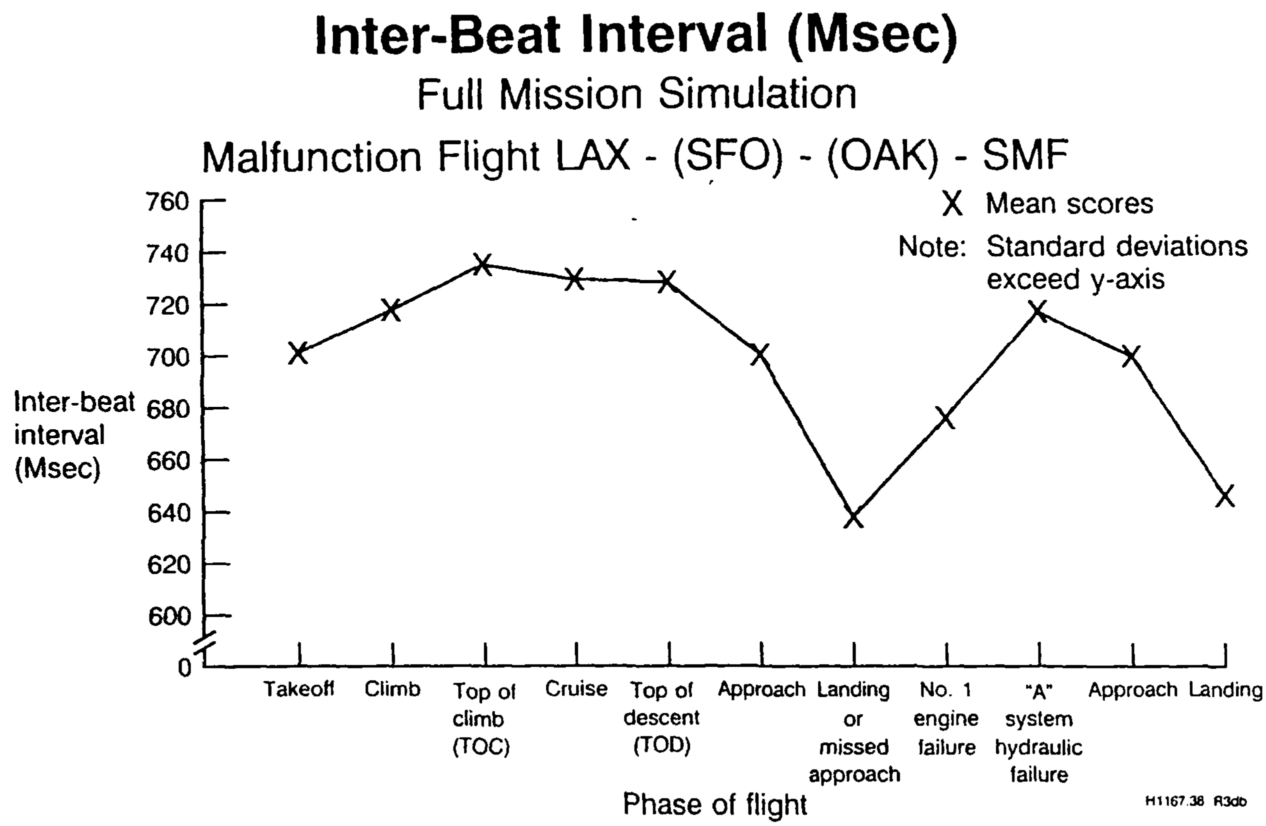


Figure 9.2.1.2-8

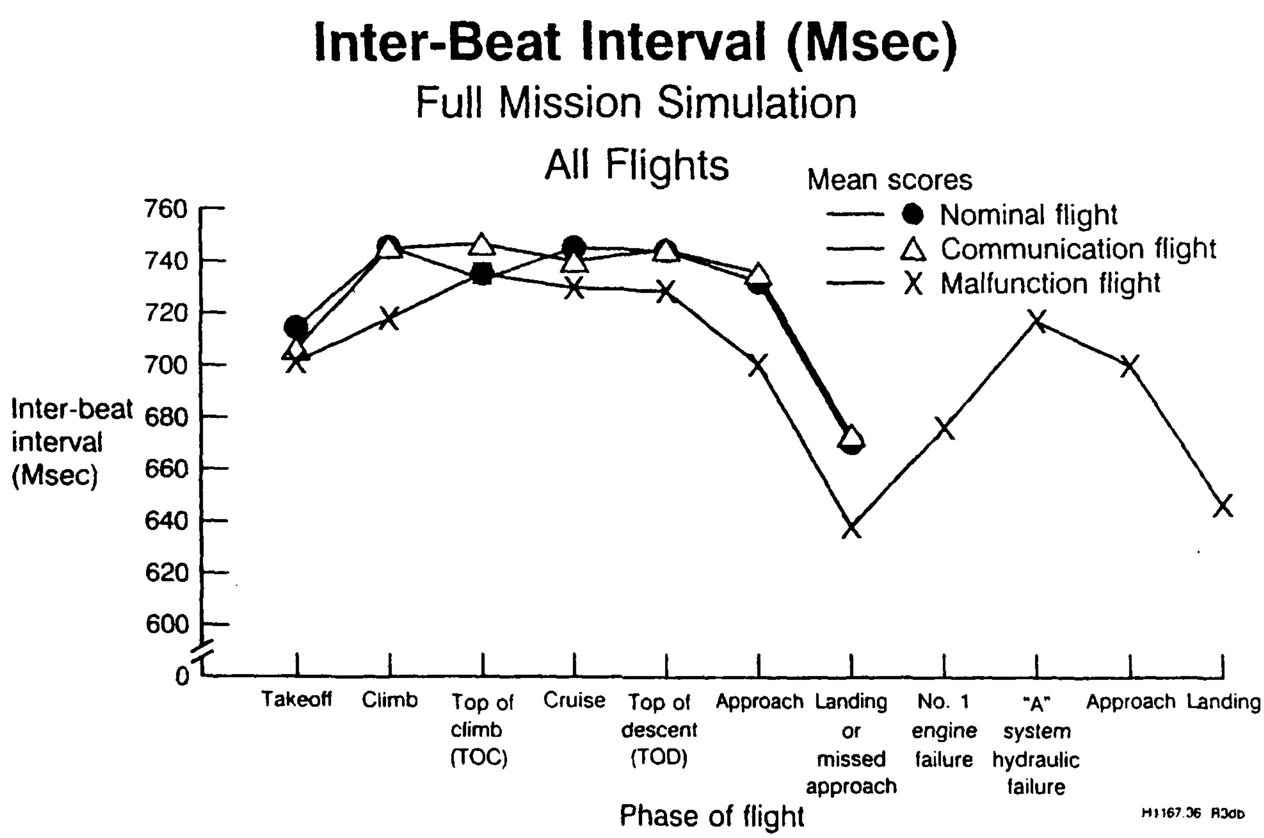


Table 9.2.1.2-3

Inter-Beat Interval (Msec)

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	714	(150)	706	(152)	701	(136)
Climb	744	(157)	745	(166)	717	(142)
Top of climb	732	(148)	746	(162)	735	(137)
Cruise	744	(147)	739	(154)	729	(138)
Top of descent	743	(161)	744	(163)	728	(142)
Approach	731	(157)	735	(163)	700	(146)
Landing or M/A	670	(136)	675	(134)	638	(123)
No. 1 engine failure					679	(135)
"A" hydraulic failure					717	(151)
Approach					700	(143)
Landing					646	(126)

H1167.00 H4db

Table 9.2.1.2-4

Inter-beat Interval (Msec)

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.87*	0.89*	0.84*
Climb	0.86*	0.89*	0.84*
Top of climb	0.88*	0.89*	0.82*
Cruise	0.86*	0.87*	0.83*
Top of descent	0.88*	0.89*	0.84*
Approach	0.89*	0.89*	0.83*
Landing or missed approach	0.89*	0.90*	0.89*
No. 1 engine failure			0.87*
"A" system hydraulics failure			0.88*
Approach			0.89*
Landing			0.92*

$r(13) = .641$*
*Significant $p<.01$

I 1167.54 H0s

A main effect for phase of flight discrimination was found, $F(6,84)=25.04$, ($MSe=2889$, $p<.01$). A oneway ANOVA found a main effect for phase of flight discrimination for the Nominal workload flight, $F(6,84)=17.09$, ($MSe=633$, $p<.01$). A Newman-Kuels range statistic was computed to determine SWAT's ability to discriminate various phases of flight from one another in the Nominal workload flight, 6 out of 21 comparisons were significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Communication workload flight, $F(6,84)=21.36$, ($MSe=504$, $p<.01$). The ability to discriminate phase of flight conditions for the Communication flight found 11 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,140)=21.79$, ($MSe=725$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 23 out of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.2-4). Seven, out of seven possible, correlations were found to be significant for the Nominal and Communication flights. Eleven, out of the eleven possible, correlations were found to be significant for the Malfunction flight.

In assessing inter-rater reliability, it was found that 87% of the subjects scores were significantly correlated with means for the 25 measurement windows.

HEART RATE VARIABILITY (IBI STANDARD DEVIATION)

Heart rate variability is the standard deviation of the R-R interbeat interval for a given measurement period.

The standard deviation of IBI found no main effect among the three workload flights, $F(2,28)=1.10$, ns (Figures 9.2.1.2-9 to 9.2.1.2-12 and Table 9.2.1.2-5).

A significant session by phase of flight interaction was found, $F(6,84)=8.64$, ($MSe=159$, $p<.01$), indicating instability of the measure's sensitivity to different task demands over time. A comparison of the Nominal-Communication flights found an interaction of session by phase of flight, $F(6,84)=5.94$, ($MSe=130$, $p<.01$). A comparison of the Nominal-Malfunction flights found an interaction of session by phase of flight, $F(6,84)=7.74$, ($MSe=143$, $p<.01$). A comparison of the Communication-Malfunction flights found an interaction of session by phase of flight, $F(6,84)=6.81$, ($MSe=140$, $p<.01$), respectively.

A main effect for phase of flight discrimination was found, $F(6,84)=3.76$, ($MSe=274$, $p<.01$). A oneway ANOVA found a main effect for phase of flight discrimination for the Communication workload flight, $F(6,84)=3.92$, ($MSe=82$, $p<.04$). The ability to discriminate phase of flight conditions for the Communication flight found 1 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,140)=3.45$, ($MSe=114$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 3 out of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.2-6). No significant correlation were found for the Nominal or Communication flights. For the Malfunction flight there was 1 significant correlation out of a possible 11.

In assessing inter-rater reliability, it was found that 33% of the subjects scores were

Figure 9.2.1.2-9

Inter-Beat Interval Standard Deviation (Msec)

Full Mission Simulation

Nominal Flight SFO - SCK

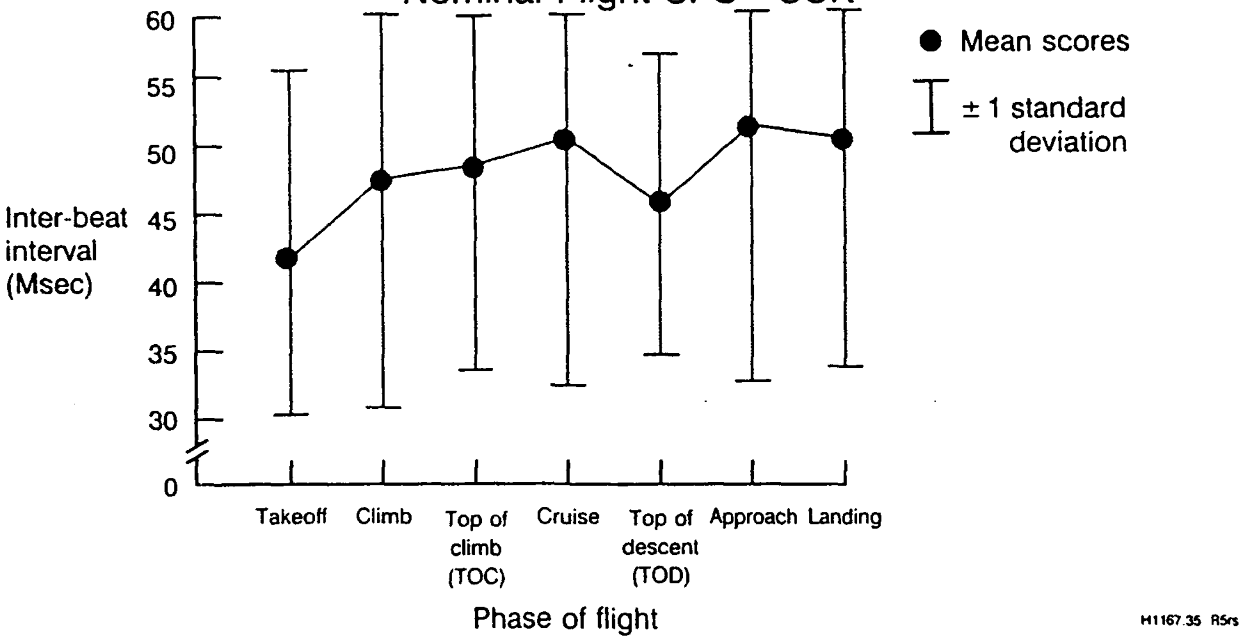


Figure 9.2.1.2-10

Inter-Beat Interval Standard Deviation (Msec)

Full Mission Simulation

Communication Flight SMF - SFO

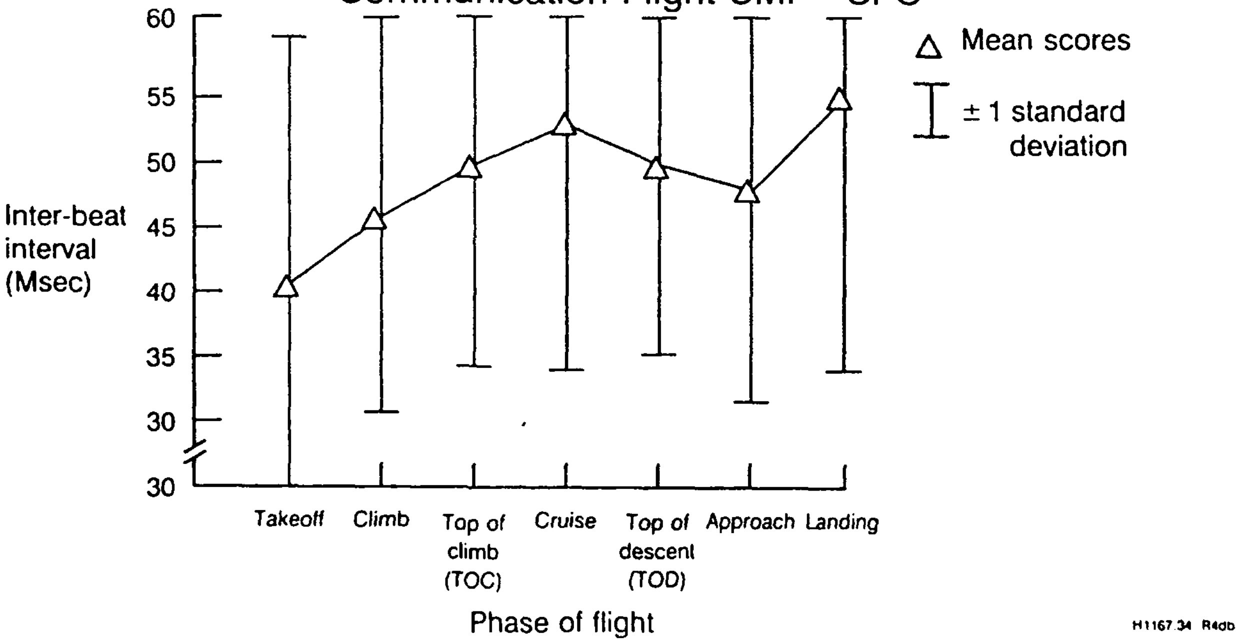


Figure 9.2.1.2-11

Inter-Beat Interval Standard Deviation (Msec)

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

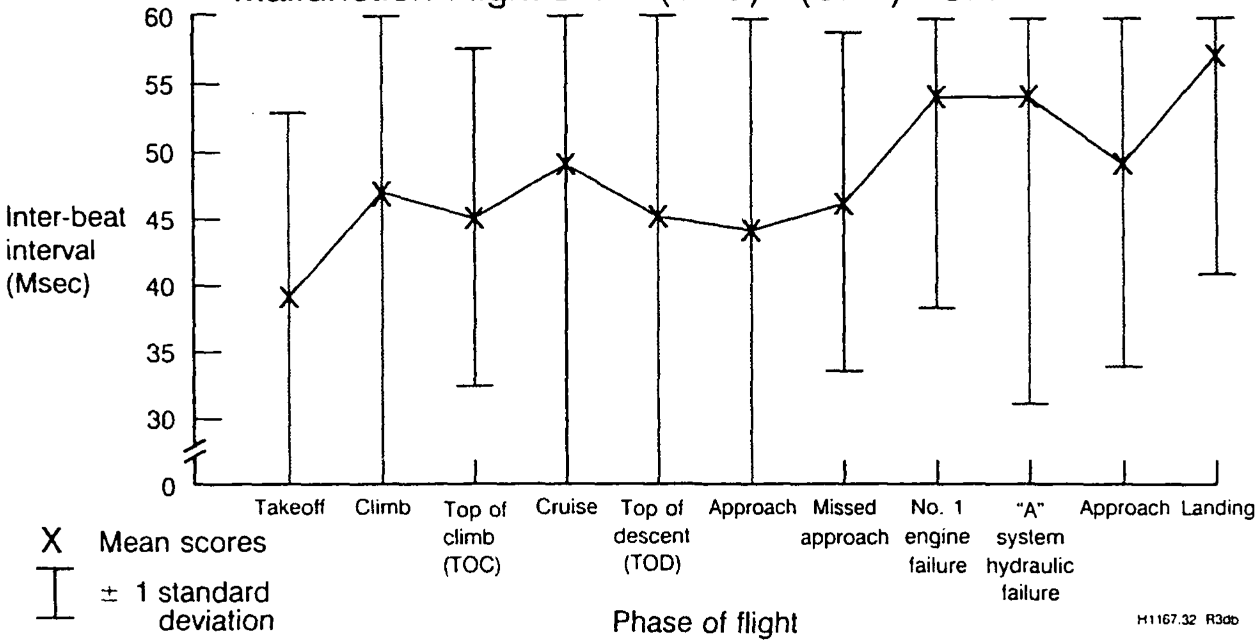


Figure 9.2.1.2-12

Inter-Beat Interval Standard Deviation (Msec)

Full Mission Simulation

All Flights

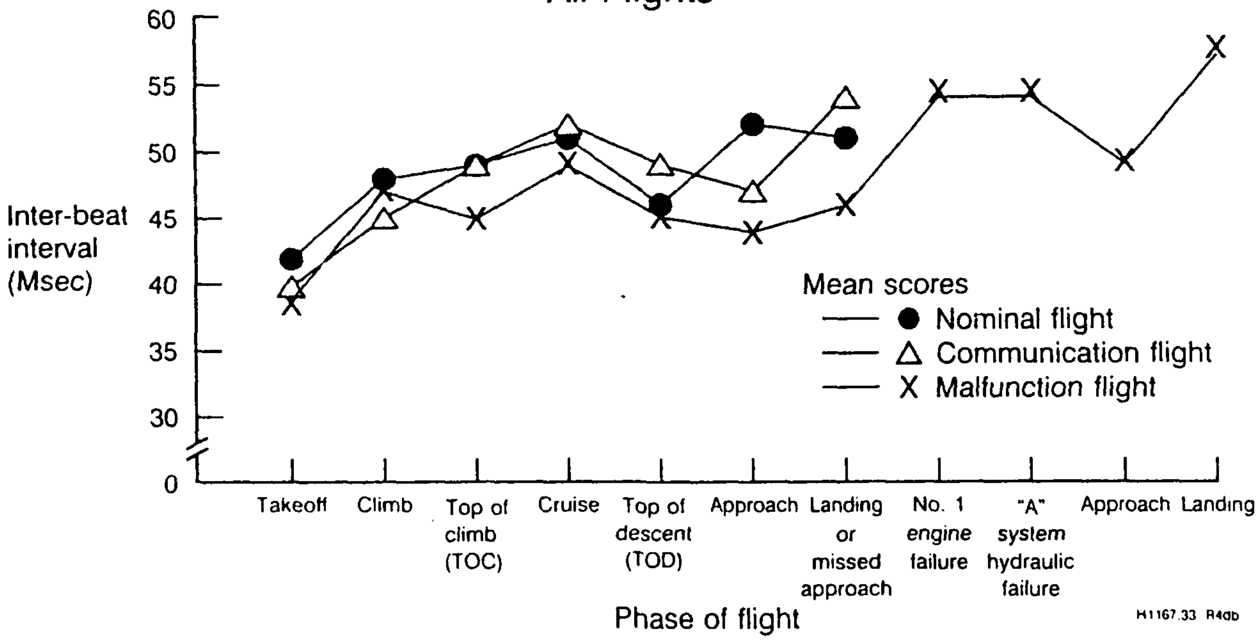


Table 9.2.1.2-5

Inter-Beat Interval Standard Deviation (Msec)

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	41.93	(14.73)	40.27	(18.07)	39.03	(13.91)
Climb	47.87	(17.52)	44.70	(15.52)	46.93	(19.50)
Top of climb	48.87	(15.77)	48.60	(15.13)	45.40	(13.80)
Cruise	50.70	(18.41)	51.90	(18.28)	49.47	(20.32)
Top of descent	45.73	(12.42)	49.03	(14.58)	45.27	(16.63)
Approach	51.53	(17.99)	46.90	(16.64)	44.47	(15.50)
Landing or M/A	50.63	(17.18)	54.33	(21.94)	45.83	(13.07)
No. 1 engine failure					53.53	(15.79)
"A" hydraulic failure					54.13	(23.71)
Approach					49.33	(15.45)
Landing					56.80	(16.65)

H1167.09 R4h

Table 9.2.1.2-6

Inter-Beat Interval Standard Deviation (Msec)

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.01	0.46	0.51
Climb	-0.04	0.32	0.31
Top of climb	0.21	0.28	0.21
Cruise	0.15	0.48	0.69*
Top of descent	-0.07	0.27	0.62
Approach	0.25	0.17	0.51
Landing or missed approach	0.17	0.38	0.15
No. 1 engine failure			0.35
"A" system hydraulics failure			0.60
Approach			0.58
Landing			-0.09

$r(13) = .641^*$
*Significant $p < .01$

I 1167.55 R5rs

significantly correlated with means for the 25 measurement windows.

POWER SPECTRAL ANALYSIS

Power spectral analyses were computed for the blood pressure (0.05 to 0.15 Hz) and respiration (0.20 to 0.40 Hz) components using a fast fourier transform of the inter-beat interval information.

BLOOD PRESSURE COMPONENT

The blood pressure component found no main effect among the three workload flights, $F < 1$ (Figures 9.2.1.2-13 to 9.2.1.2-16 and Table 9.2.1.2-7).

A strong trend for a three-way interaction was found for session by workload by phase of flight, $F(12,168)=2.13$, ($MSe=0.58$, $p<.02$). The interaction was not predicted, and indicates the instability of the measure over testing periods. When comparing the Nominal-Communication another strong trend for a three-way interaction was found for session by workload by phase of flight, $F(6,84)=1.95$, ($MSe=0.64$, $p<.08$). In addition, comparing the Communication-Malfunction another strong trend for a three-way interaction was found for session by workload by phase of flight, $F(6,84)=2.70$, ($MSe=0.61$, $p<.02$).

A main effect for phase of flight discrimination was found, $F(6,84)=12.64$, ($MSe=1.68$, $p<.01$). A oneway ANOVA found a main effect for phase of flight discrimination for the Nominal workload flight, $F(6,84)=5.12$, ($MSe=0.80$, $p<.01$). The ability to discriminate phase of flight conditions for the Nominal flight found 2 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Communication workload flight, $F(6,84)=8.06$, ($MSe=0.58$, $p<.01$). The ability to discriminate phase of flight conditions for the Communication flight found 6 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,140)=8.14$, ($MSe=0.51$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 13 out of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.2-8). No significant correlations were found for the Nominal flight. For the Communication and Malfunction flights there were 2, out of a possible 7, and 3, out of a possible 11, significant correlations.

In assessing inter-rater reliability, it was found that 80% of the subjects scores were significantly correlated with means for the 25 measurement windows.

RESPIRATION COMPONENT

The respiration component found no main effect among the three workload flights, $F < 1$ (Figures 9.2.1.2-17 to 9.2.1.2-20 and Table 9.2.1.2-9).

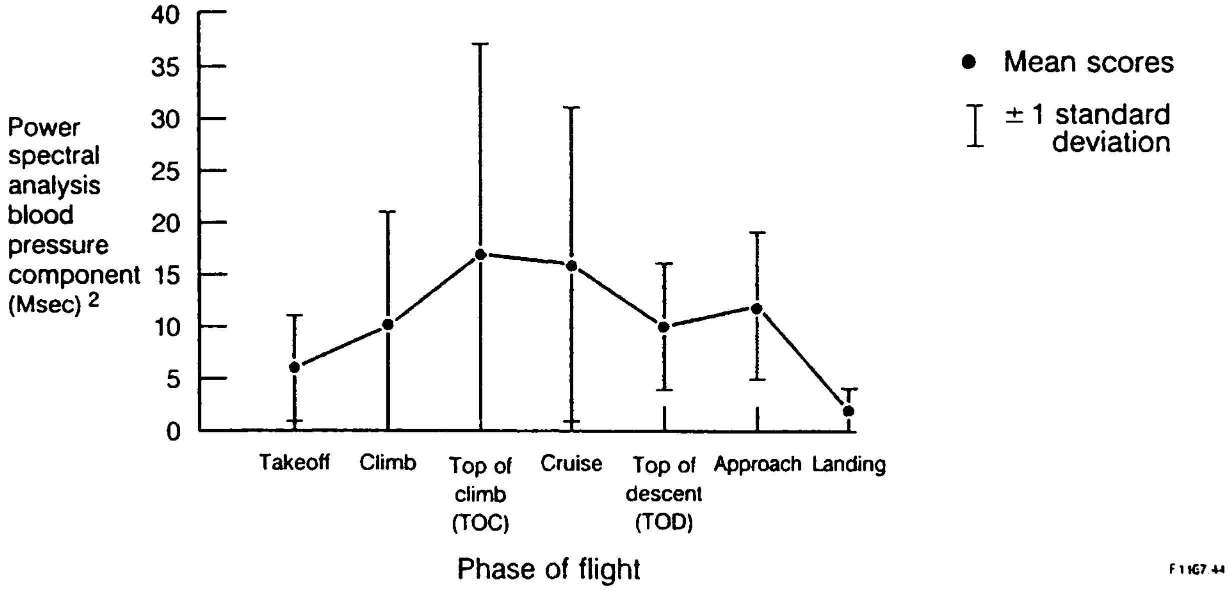
A main effect for phase of flight discrimination was found, $F(6,84)=6.81$, ($MSe=0.07$, $p<.01$). A oneway ANOVA found a strong trend for a main effect for phase of flight discrimination for the Nominal workload flight, $F(6,84)=2.51$, ($MSe=0.036$, $p<.03$). A oneway ANOVA found a main effect for phase of flight discrimination for the Communication workload flight, $F(6,84)=3.03$, ($MSe=0.06$, $p<.01$). A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,140)=2.99$, ($MSe=0.01$, $p<.01$). Although the separate oneway ANOVAs found a

Figure 9.2.1.2-13

Power Spectral Analysis (Blood Pressure Component)

Full Mission Simulation

Nominal Flight SFO - SCK



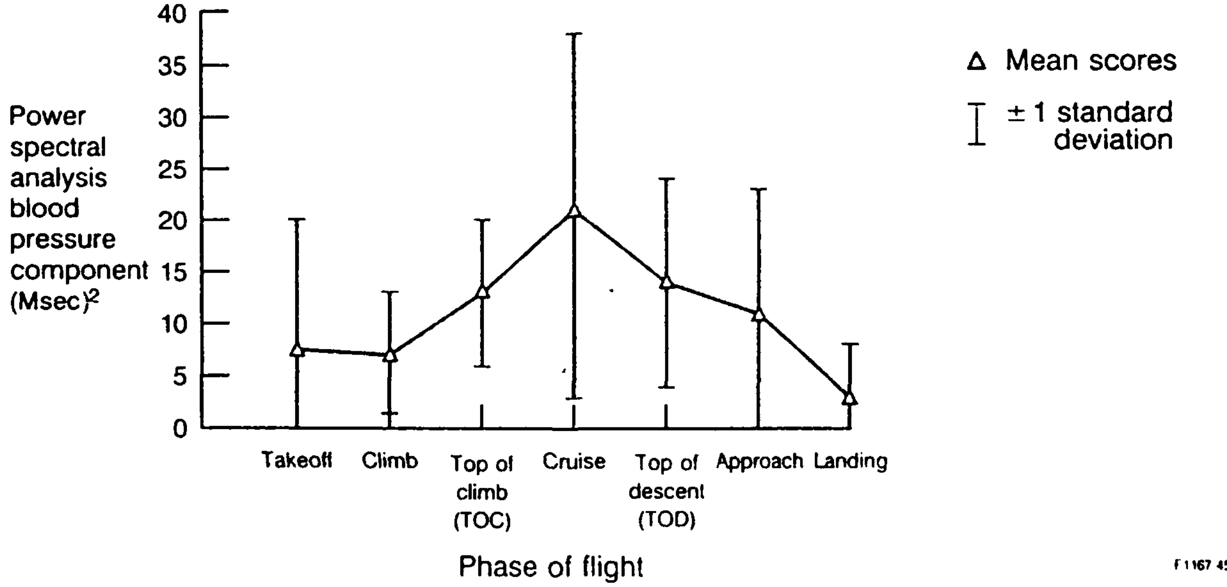
F1167.44 R7

Figure 9.2.1.2-14

Power Spectral Analysis (Blood Pressure Component)

Full Mission Simulation

Communications Flight SMF - SFO



F1167.45 R7

Figure 9.2.1.2-15

Power Spectral Analysis (Blood Pressure Component)

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

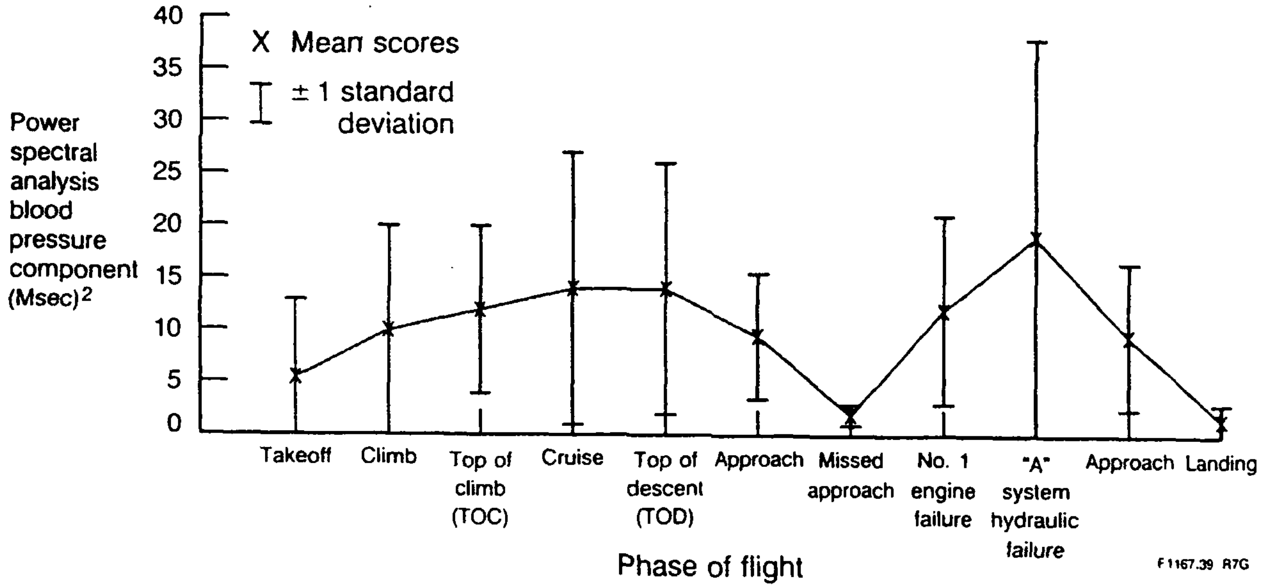


Figure 9.2.1.2-16

Power Spectral Analysis Blood Pressure Component

Full Mission Simulation

All Flights

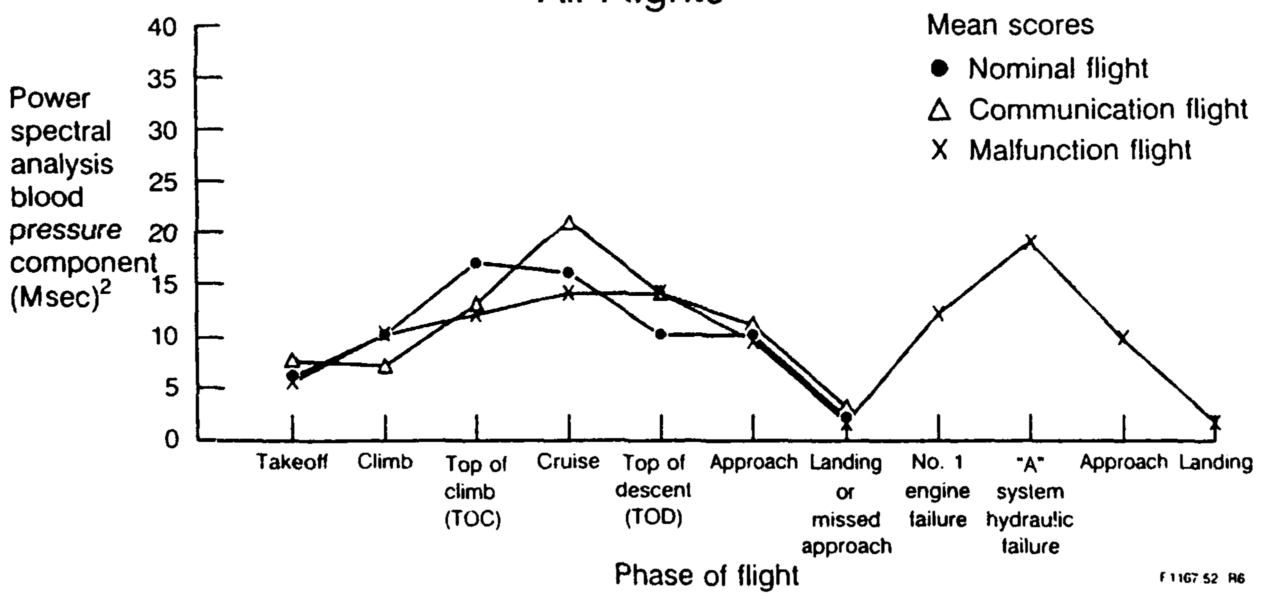


Table 9.2.1.2-7

Power Spectral Analysis (Blood Pressure Component)

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	6.2	(5.1)	7.5	(12.3)	5.5	(7.3)
Climb	9.6	(10.9)	7.3	(5.9)	10.0	(9.5)
Top of climb	16.7	(20.6)	13.0	(7.5)	11.6	(8.1)
Cruise	15.8	(15.3)	20.5	(17.6)	14.3	(13.1)
Top of descent	10.0	(6.2)	13.9	(9.7)	14.4	(11.8)
Approach	11.6	(7.4)	10.6	(12.2)	9.5	(6.1)
Landing or M/A	1.8	(1.8)	3.4	(4.7)	1.8	(1.2)
No. 1 engine failure					11.8	(8.8)
"A" hydraulic failure					18.8	(18.6)
Approach					9.5	(7.3)
Landing					1.6	(1.7)

H1167 10 R4do

Table 9.2.1.2-8

Power Spectral Analysis (Blood Pressure Component)

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.54	0.93*	0.96*
Climb	0.28	0.18	0.61
Top of climb	0.59	0.16	0.44
Cruise	0.51	0.38	0.86*
Top of descent	-0.18	0.59	0.48
Approach	0.17	0.66*	0.21
Landing or missed approach	0.32	0.50	0.19
No. 1 engine failure			0.53
"A" system hydraulics failure			0.69*
Approach			0.43
Landing			0.48

$r(13) = .641$*
*Significant $p < .01$

H1167 56 R7rs

Figure 9.2.1.2-17

Power Spectral Analysis (Respiration Component)

Full Mission Simulation
Nominal Flight SFO - SCK

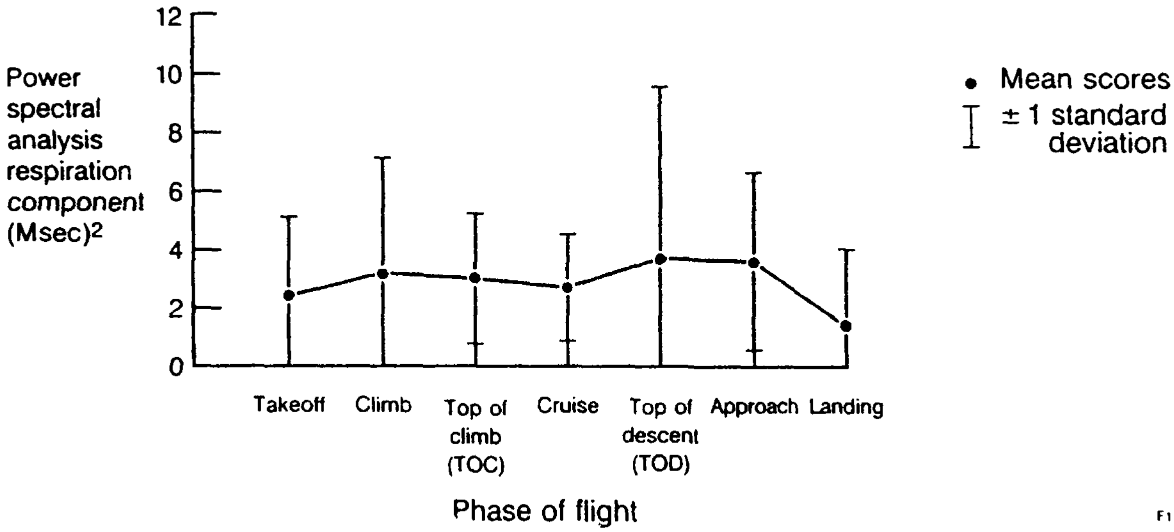


Figure 9.2.1.2-18

Power Spectral Analysis (Respiration Component)

Full Mission Simulation
Communications Flight SMF-SFO

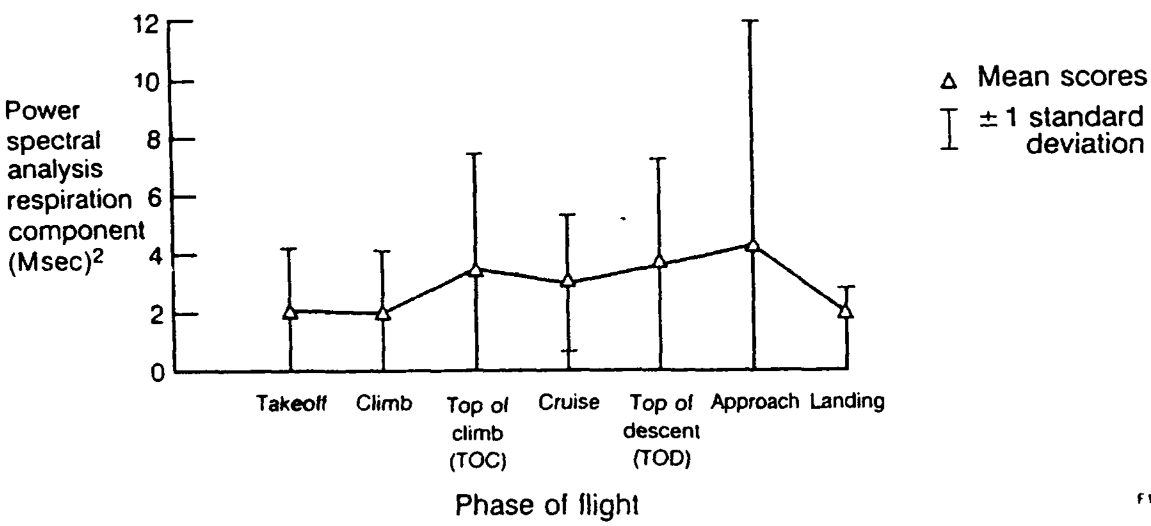


Figure 9.2.1.2-19

Power Spectral Analysis (Respiration Component)

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

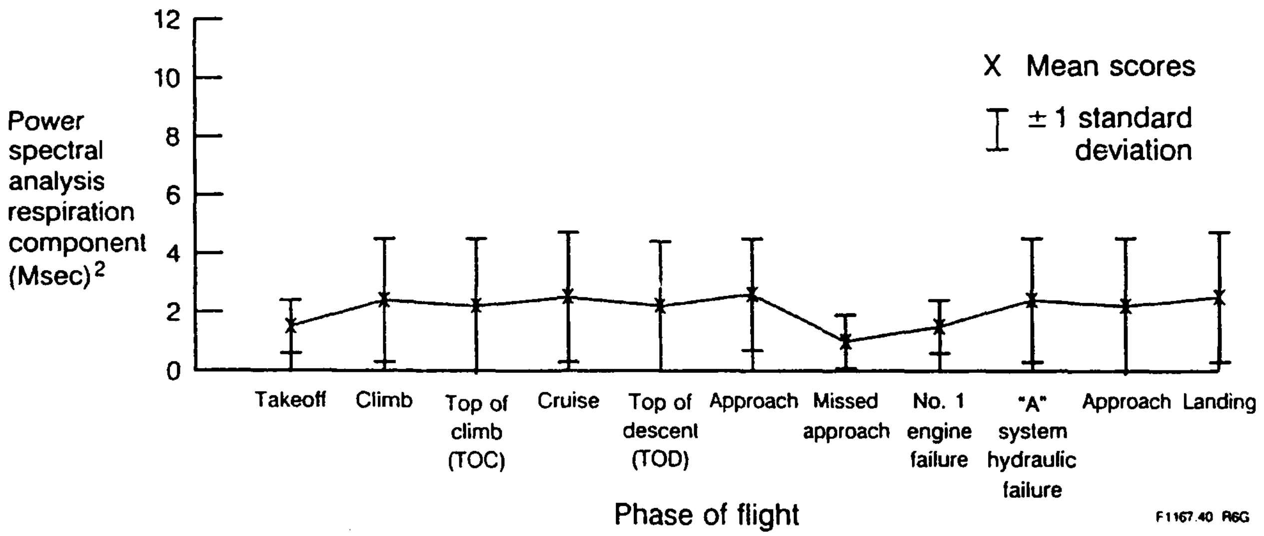


Figure 9.2.1.2-20

Power Spectral Analysis (Respiration Component)

Full Mission Simulation

All Flights

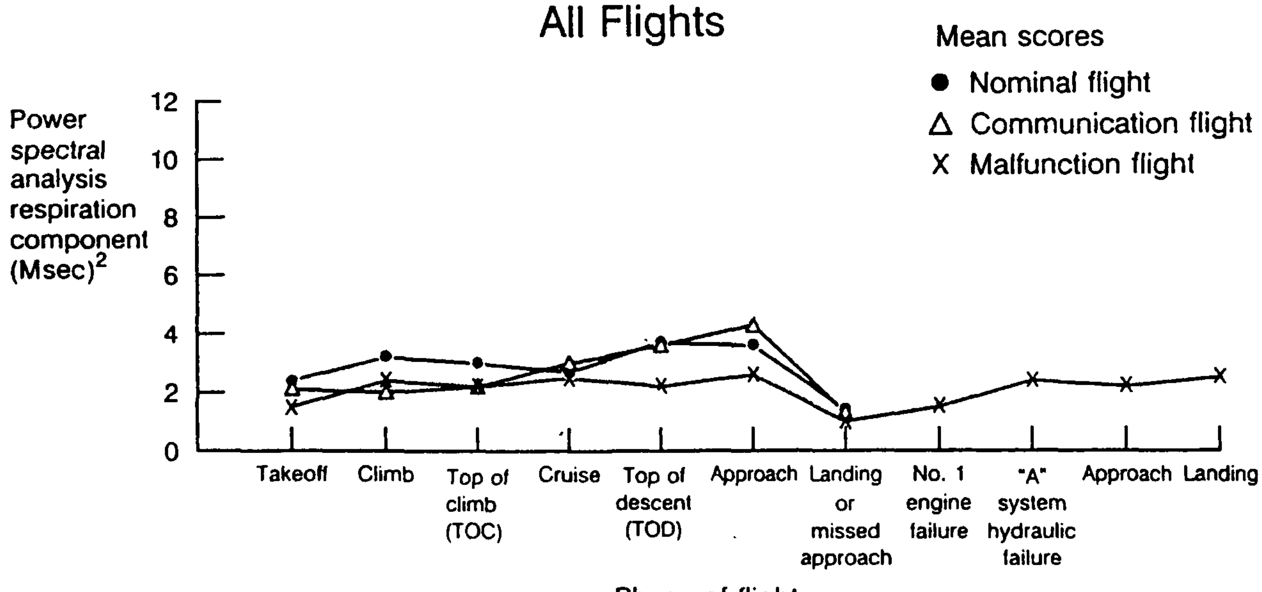


Table 9.2.1.2-9

Power Spectral Analysis (Respiration Component)

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	2.4	(2.7)	2.1	(2.2)	1.5	(0.9)
Climb	3.2	(3.9)	2.0	(2.1)	2.4	(2.1)
Top of climb	3.0	(2.3)	3.5	(3.9)	2.2	(2.3)
Cruise	2.7	(1.8)	3.0	(2.3)	2.5	(2.2)
Top of descent	3.7	(5.7)	3.6	(3.6)	2.2	(2.2)
Approach	3.6	(3.0)	4.3	(7.7)	2.6	(1.9)
Landing or M/A	1.4	(2.6)	1.3	(1.5)	1.0	(0.8)
No. 1 engine failure					1.5	(0.9)
"A" hydraulic failure					2.4	(2.1)
Approach					2.2	(2.3)
Landing					2.5	(2.2)

H1167.11 R4dD

Table 9.2.1.2-10

Power Spectral Analysis (Respiration Component)

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	-0.14	-0.14	0.16
Climb	-0.10	-0.15	-0.04
Top of climb	-0.17	-0.13	0.13
Cruise	-0.25	-0.22	0.16
Top of descent	-0.13	-0.16	0.40
Approach	-0.24	-0.15	0.21
Landing or missed approach	-0.28	0.13	-0.26
No. 1 engine failure			-0.39
"A" system hydraulics failure			0.11
Approach			0.13
Landing			-0.17

r(13) = .641*
*Significant p< .01

F1167.57 R?fs

significant main effect for phase of flight discrimination, the Newman-Kuels range statistic could not discriminate any of the phases of flight from one another within the individual flights.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.2-10). No significant correlations were found for the Nominal, Communication, or Malfunction flight.

In assessing inter-rater reliability, it was found that 47% of the subjects scores were significantly correlated with means for the 25 measurement windows.

9.2.1.3 PERFORMANCE MEASURES

Control input activity was measured by calculating flight control position changes over time. The position of the flight controls was collected at a rate of 10 Hz. If the position of a flight control (i.e., wheel, column, or pedals) moved more than 2.5% of the total throw available then the input activity counter was incriminated. Each control input activity index is computed over time, so that control activity is expressed in inputs per minute. Following normal convention, wheel input activity controls roll, column input activity controls pitch, and pedal input activity controls yaw.

WHEEL (AILERON) CONTROL INPUTS

Wheel control input activity found a main effect among the three workload flights, $F(2,30)=13.91$, ($MSe=52$, $p<.01$). A workload by phase of flight interaction was found as well, $F(12,180)=9.74$, ($MSe=35$, $p<.01$) (Figures 9.2.1.3-1 to 9.2.1.3-4 and Table 9.2.1.3-1).

In addition, a three way interaction of session by workload by phase of flight was found to be significant, $F(12,180)=2.29$, ($MSe=25$, $p<.01$). This interaction shows some instability of the measure in assessing workload differences with repeated testing. Another three way interaction of the same factors was found when comparing the Nominal-Malfunction flights, $F(6,90)=4.54$, ($MSe=22$, $p<.01$).

A comparison of the Nominal-Communication flights found a main effect of workload and an interaction of workload by phase of flight, $F(1,15)=8.84$, ($MSe=0.75$, $p<.01$) and $F(6,90)=13.33$, ($MSe=32$, $p<.01$), respectively. A comparison of the Nominal-Malfunction flights found a significant main effect of workload and an interaction of workload by phase of flight, $F(1,15)=22.26$, ($MSe=57$, $p<.01$) and $F(6,90)=18.60$, ($MSe=10.90$, $p<.01$), respectively. A comparison of the Communication-Malfunction flights found an interaction of workload by phase of flight, $F(6,90)=3.97$, ($MSe=29$, $p<.01$), respectively.

A main effect for phase of flight discrimination was found, $F(6,90)=84.50$, ($MSe=80$, $p<.01$). A oneway ANOVA found a main effect for phase of flight discrimination for the Nominal workload flight, $F(6,90)=56.81$, ($MSe=37$, $p<.01$). A Newman-Kuels range statistic was computed to determine SWAT's ability to discriminate various phases of flight from one another in the Nominal workload flight, 10 out of 21 comparisons were significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Communication workload flight, $F(6,90)=35.93$, ($MSe=20$, $p<.01$). The ability to discriminate phase of flight conditions for the Communication flight found 8 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,150)=71.69$, ($MSe=37$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 35 out

Figure 9.2.1.3-1

Wheel (Aileron) Control Inputs (per Minute)

Full Mission Simulation

Nominal Flight SFO - SCK

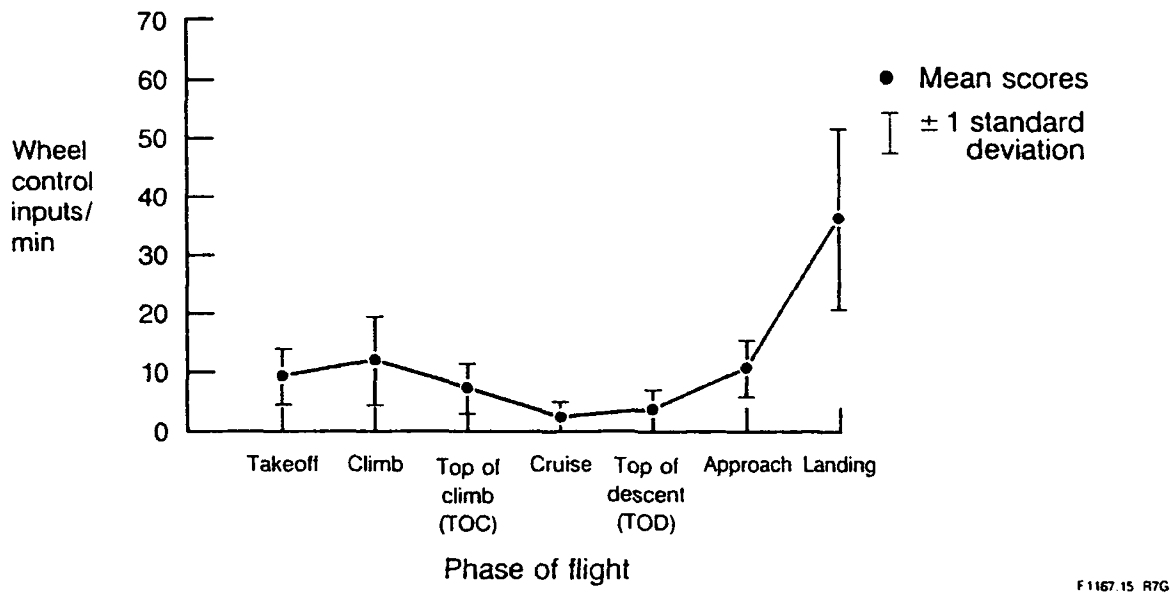


Figure 9.2.1.3-2

Wheel (Aileron) Control Inputs (per Minute)

Full Mission Simulation

Communications Flight SMF - SFO

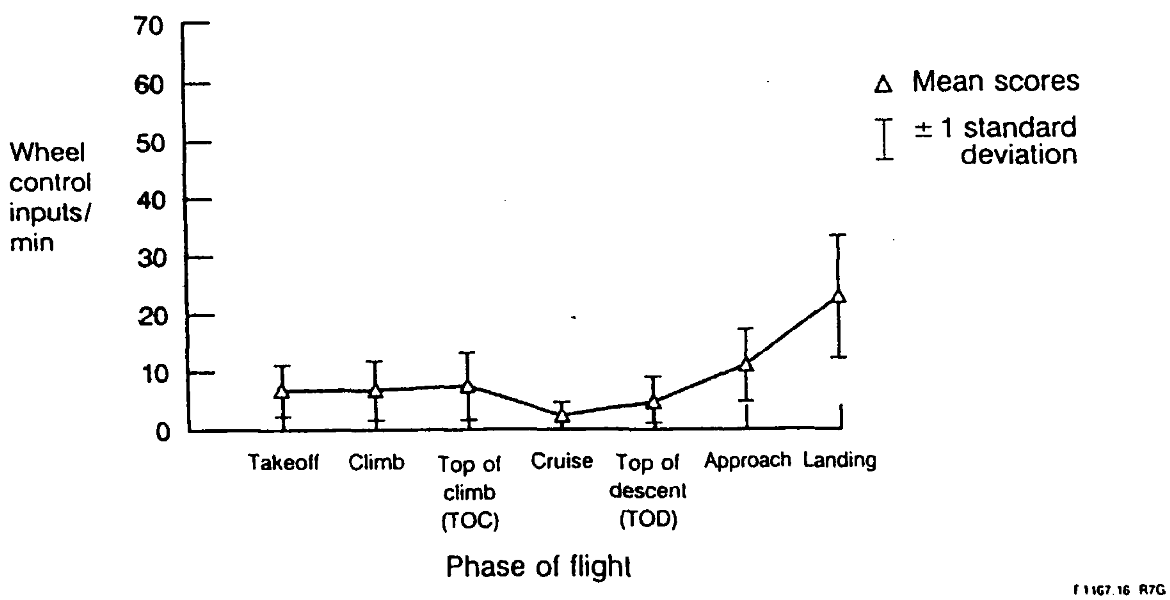


Figure 9.2.1.3-3

Wheel (Aileron) Control Inputs (per Minute)

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

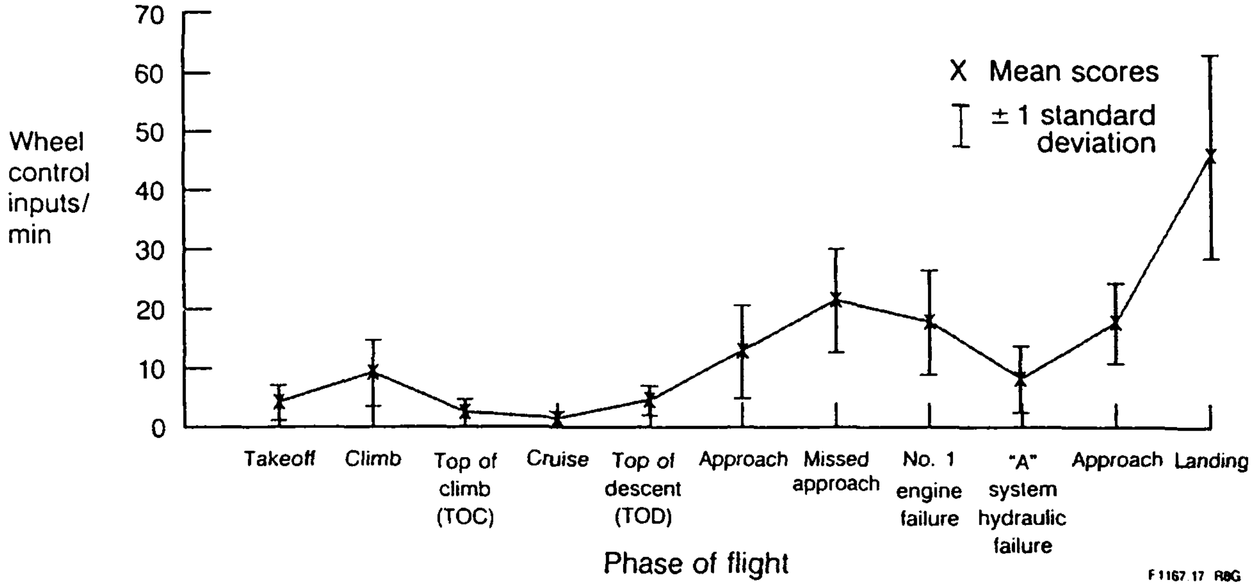


Figure 9.2.1.3-4

Wheel (Aileron) Control Inputs (per Minute)

Full Mission Simulation

All Flights

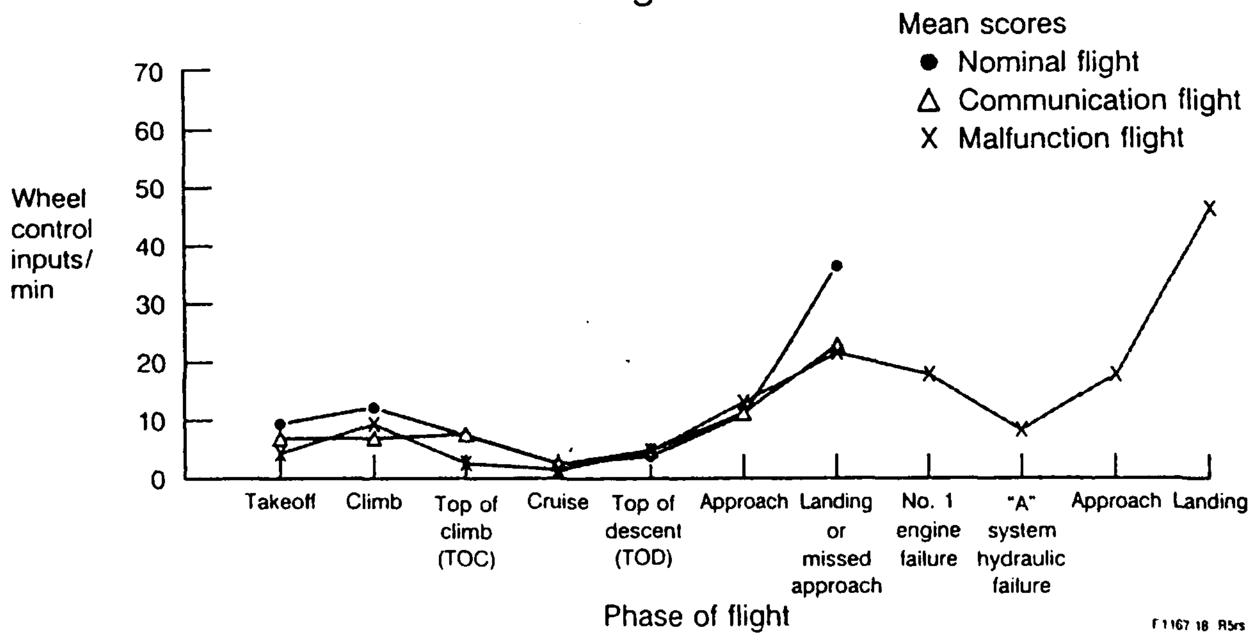


Table 9.2.1.3-1

Wheel (Aileron) Control Input

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	9.4	(4.7)	6.9	(4.4)	4.4	(2.9)
Climb	12.2	(7.5)	6.9	(5.1)	9.8	(5.4)
Top of climb	7.4	(4.3)	7.6	(5.8)	2.6	(2.2)
Cruise	2.5	(2.7)	2.5	(2.4)	1.3	(1.5)
Top of descent	3.8	(3.5)	4.8	(3.4)	5.0	(2.6)
Approach	10.8	(4.8)	11.2	(6.3)	13.1	(7.3)
Landing or M/A	36.4	(15.6)	23.0	(10.6)	22.6	(9.3)
No. 1 engine failure					18.4	(8.7)
"A" hydraulic failure					8.2	(5.2)
Approach					17.9	(6.7)
Landing					46.0	(16.5)

H1167 12 R4ob

Table 9.2.1.3-2

Wheel (Aileron) Control Inputs

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.38	0.11	0.36
Climb	0.70*	0.69*	0.59
Top of climb	0.72*	0.73*	0.64*
Cruise	-0.49	0.46	0.05
Top of descent	0.40	0.36	0.30
Approach	0.78*	0.58	0.66*
Landing or missed approach	0.51	0.30	0.51
No. 1 engine failure			0.75*
"A" system hydraulics failure			0.72*
Approach			0.47
Landing			0.72*

$r(14) = 0.623$*

* Significant $p < 0.01$

of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.3-2). For the Nominal flight there was three significant correlation out of a possible seven. For the Communication and Malfunction flights there were 2 out 7, and 5 out of 11, significant correlations, respectively.

In assessing inter-rater reliability, it was found that all of the subjects scores (100%) were significantly correlated with means for the 25 measurement windows.

COLUMN (ELEVATOR) CONTROL INPUTS

Column control input activity found a main effect among the three workload flights, $F(2,30)=20.17$, ($MSe=27$, $p<.01$). A workload by phase of flight interaction was found as well, $F(12,180)=18.88$, ($MSe=27$, $p<.01$) (Figures 9.2.1.3-5 to 9.2.1.3-8 and Table 9.2.1.3-3).

A comparison of the Nominal-Communication flights found a main effect of workload and an interaction of workload by phase of flight, $F(1,15)=27.60$, ($MSe=24$, $p<.01$) and $F(6,90)=23.27$, ($MSe=26$, $p<.01$), respectively. A comparison of the Nominal-Malfunction flights found a significant main effect of workload and an interaction of workload by phase of flight, $F(1,15)=33.39$, ($MSe=29$, $p<.01$) and $F(6,90)=28.04$, ($MSe=31$, $p<.01$), respectively. A comparison of the Communication-Malfunction flights found a strong trend for an interaction of workload by phase of flight, $F(6,90)=2.58$, ($MSe=24$, $p<.01$).

A main effect for phase of flight discrimination was found, $F(6,90)=169.83$, ($MSe=103$, $p<.01$). A oneway ANOVA found a main effect for phase of flight discrimination for the Nominal workload flight, $F(6,90)=209.36$, ($MSe=24$, $p<.01$). A Newman-Kuels range statistic was computed to determine SWAT's ability to discriminate various phases of flight from one another in the Nominal workload flight, 10 out of 21 comparisons were significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Communication workload flight, $F(6,90)=99.34$, ($MSe=22$, $p<.01$). The ability to discriminate phase of flight conditions for the Communication flight found 10 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,150)=79.92$, ($MSe=45$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 22 out of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.3-4). For the Nominal and Communication flights none of the measurement windows showed a significant correlation. For the Malfunction flights there were 3, out of 11 possible, significant correlations.

In assessing inter-rater reliability, it was found that all of the subjects scores (100%) were significantly correlated with means for the 25 measurement windows.

PEDAL (RUDDER) CONTROL INPUTS

Pedal control input activity found a main effect among the three workload flights, $F(2,30)=26.43$, ($MSe=15$, $p<.01$). A workload by phase of flight interaction was found

Figure 9.2.1.3-5

Column (Elevator) Control Inputs (per Minute)

Full Mission Simulation

Nominal Flight SFO - SCK

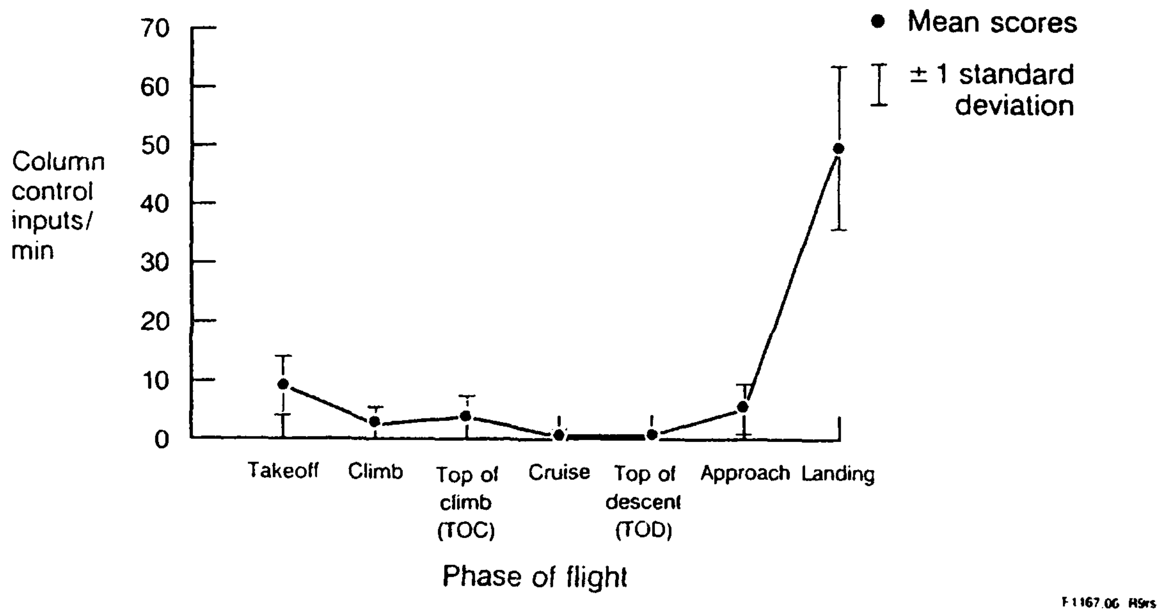


Figure 9.2.1.3-6

Column (Elevator) Control Inputs (per Minute)

Full Mission Simulation

Communications Flight SMF - SFO

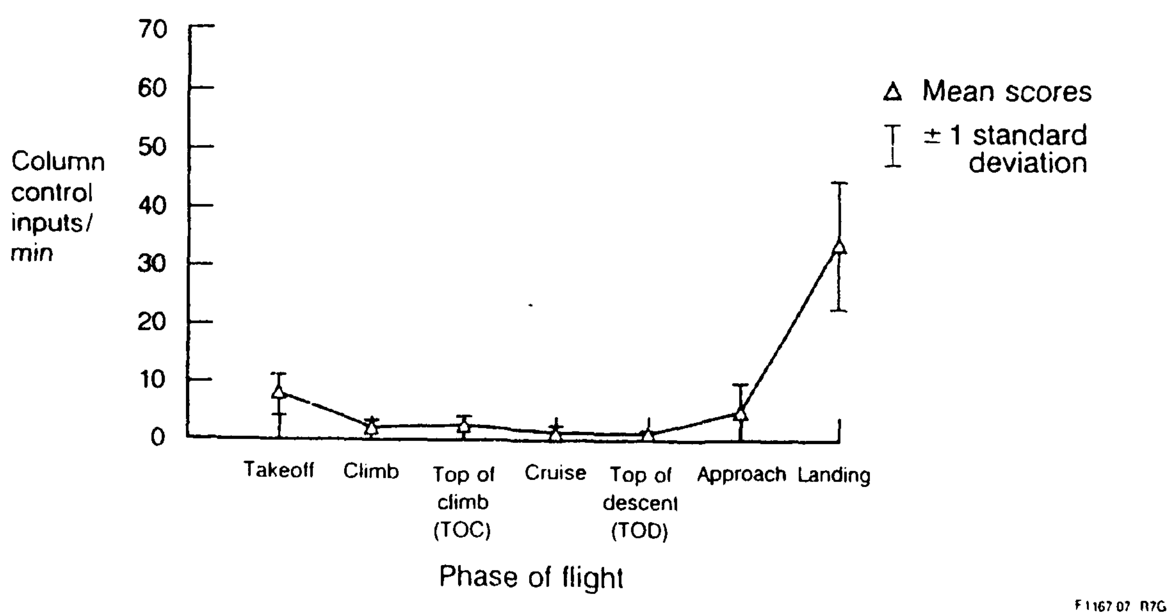


Figure 9.2.1.3-7

Column (Elevator) Control Inputs (per Minute)

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

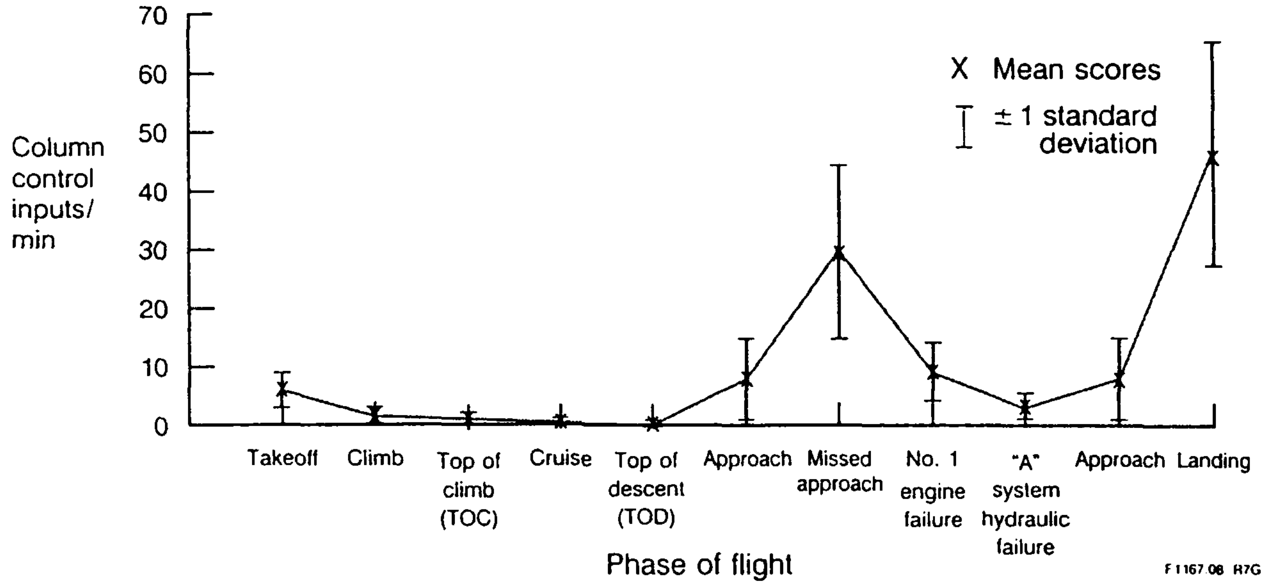


Figure 9.2.1.3-8

Column (Elevator) Control Inputs (per Minute)

Full Mission Simulation

All Flights

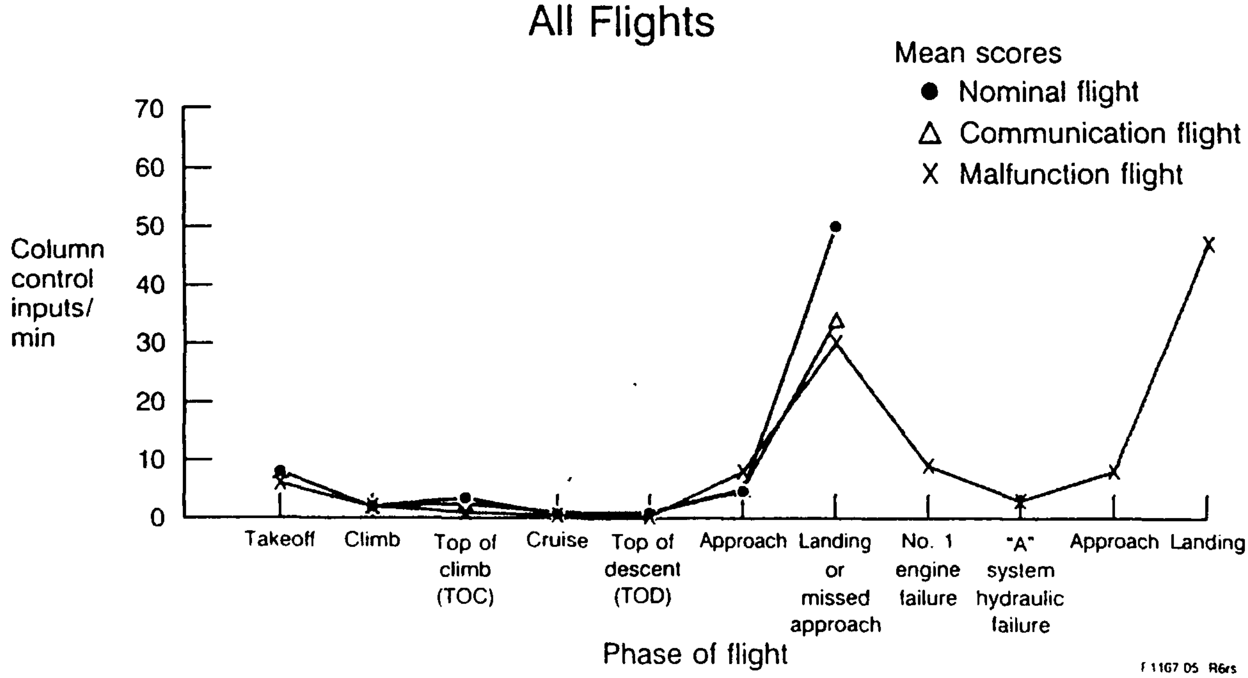


Table 9.2.1.3-3

Column (Elevator) Control Input

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal		Communication		Malfunction	
	Mean	SD	Mean	SD	Mean	SD
Takeoff	8.1	(4.4)	7.9	(3.5)	6.7	(2.9)
Climb	2.3	(2.7)	2.0	(1.7)	1.9	(2.1)
Top of climb	3.5	(3.0)	2.4	(2.0)	0.8	(1.0)
Cruise	0.7	(1.0)	1.2	(1.6)	0.3	(0.4)
Top of descent	0.8	(0.6)	1.0	(1.1)	0.3	(0.4)
Approach	4.7	(3.8)	4.8	(5.4)	8.4	(6.6)
Landing or M/A	50.0	(12.1)	33.6	(11.3)	31.0	(14.1)
No. 1 engine failure					10.0	(5.3)
"A" hydraulic failure					3.0	(2.0)
Approach					8.1	(6.3)
Landing					47.7	(17.4)

H1167 13 R3cD

Table 9.2.1.3-4

Column (Elevator) Control Inputs

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.54	0.53	0.41
Climb	0.39	0.28	0.75*
Top of climb	0.33	0.03	0.32
Cruise	-0.19	0.03	-0.31
Top of descent	-0.11	0.17	0.66*
Approach	0.28	0.52	0.72*
Landing or missed approach	0.01	-0.52	0.43
No. 1 engine failure			0.55
"A" system hydraulics failure			0.38
Approach			0.44
Landing			0.31

$r(14) = 0.623$*
* Significant $p < 0.01$

I 1167 10 R8G

as well, $F(12,180)=12.59$, ($MSe=17$, $p<.01$) (Figures 9.2.1.3-9 to 9.2.1.3-12 and Table 9.2.1.3-5).

A comparison of the Nominal-Communication flights found a strong trends for both a main effect of workload and an interaction of workload by phase of flight, $F(1,15)=7.26$, ($MSe=12$, $p<.01$) and $F(6,90)=2.84$, ($MSe=17$, $p<.01$), respectively. A comparison of the Nominal-Malfunction flights found a significant main effect of workload and an interaction of workload by phase of flight, $F(1,15)=41.13$, ($MSe=19$, $p<.01$) and $F(6,90)=16.46$, ($MSe=22$, $p<.01$), respectively. A comparison of the Communication-Malfunction flights found a for main effect of workload and an interaction of workload by phase of flight, , $F(1,15)=23.70$, ($MSe=14$, $p<.01$) and $F(6,90)=19.07$, ($MSe=12$, $p<.01$), respectively.

A main effect for phase of flight discrimination was found, $F(6,90)=37.96$, ($MSe=106$, $p<.01$). A oneway ANOVA found a main effect for phase of flight discrimination for the Nominal workload flight, $F(6,90)=30.63$, ($MSe=36$, $p<.01$). A Newman-Kuels range statistic was computed to determine SWAT's ability to discriminate various phases of flight from one another in the Nominal workload flight, 11 out of 21 comparisons were significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Communication workload flight, $F(6,90)=32.19$, ($MSe=22$, $p<.01$). The ability to discriminate phase of flight conditions for the Communication flight found 10 out of 21 comparisons significant. A oneway ANOVA found a main effect for phase of flight discrimination for the Malfunction workload flight, $F(10,150)=13.93$, ($MSe=27$, $p<.01$). The ability to discriminate phase of flight conditions for the Malfunction flight found 18 out of 55 comparisons significant.

Test-retest reliability was computed by comparing the pilot's ratings for session one and two for the separate measurement windows (Table 9.2.1.3-6). For the Nominal there were two significant correlations out of seven. For the Communication flight none of the measurement windows showed a significant correlation. For the Malfunction flights there were 3, out of 11 possible, significant correlations.

In assessing inter-rater reliability, it was found that all of the subjects scores (100%) were significantly correlated with means for the 25 measurement windows.

9.3 RELATIONSHIP OF MEASURES

As was done for the Part-Task simulation, a correlation matrix was generated for the means for each of the workload measures from the 25 measurement windows (Table 9.3-1).

Again the reader should use caution when drawing conclusions from the correlation matrix. Similar to the Part-Task simulation, the correlation matrix is computed on the means for the various measures from the various workload windows: seven windows each from the Nominal and Communication flights, along with the 11 from the Malfunction flight. The correlation matrix should be viewed simply as an aid in understanding the global trends of covariation of the workload measures in assessing the task demands of the three flights.

9.4 PRINCIPAL COMPONENT ANALYSIS

Another Principal Component Analysis (PCA) was performed on the data from the Full-Mission simulation (Table 9.4-1). The interpretation of the factor loadings in any sort of a factor analysis should be done with caution.

Figure 9.2.1.3-9

Pedal (Rudder) Control Inputs (per Minute)

Full Mission Simulation

Nominal Flight SFO - SCK

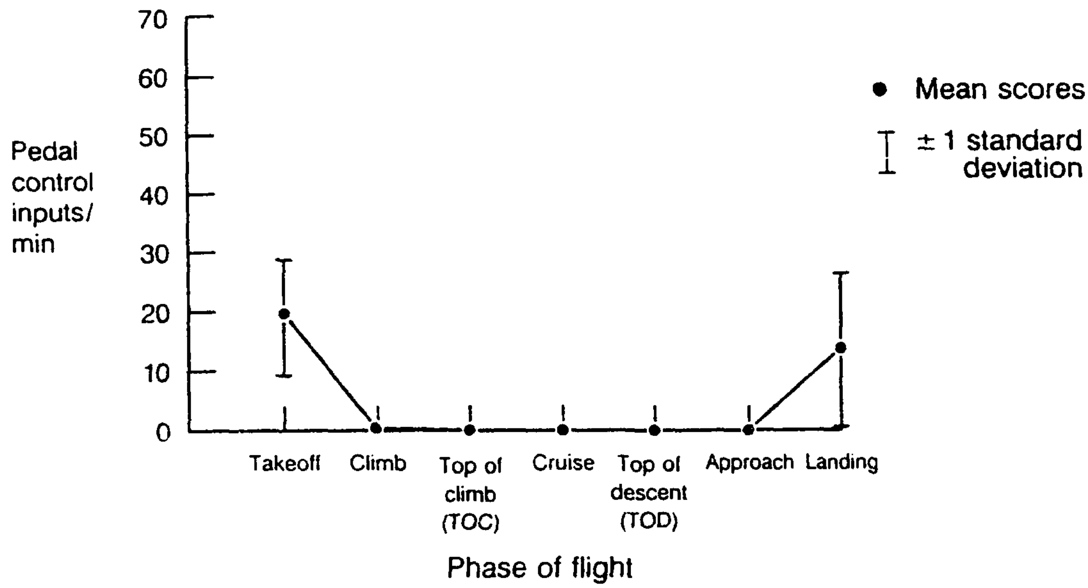


Figure 9.2.1.3-10

Pedal (Rudder) Control Inputs (per Minute)

Full Mission Simulation

Communications Flight SMF - SFO

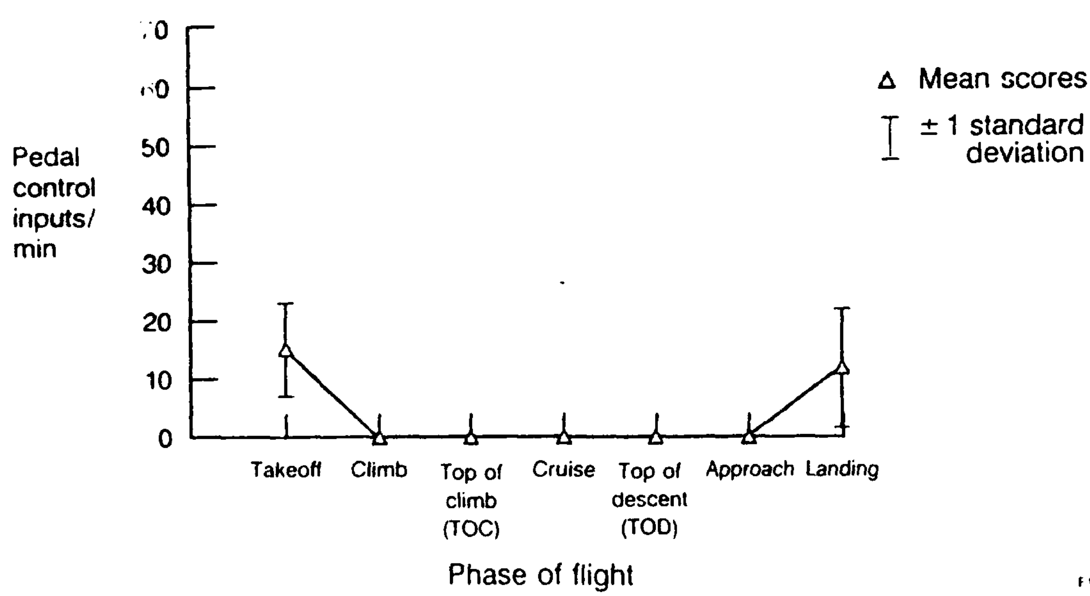


Figure 9.2.1.3-11

Pedal (Rudder) Control Inputs (per Minute)

Full Mission Simulation

Malfunction Flight LAX - (SFO) - (OAK) - SMF

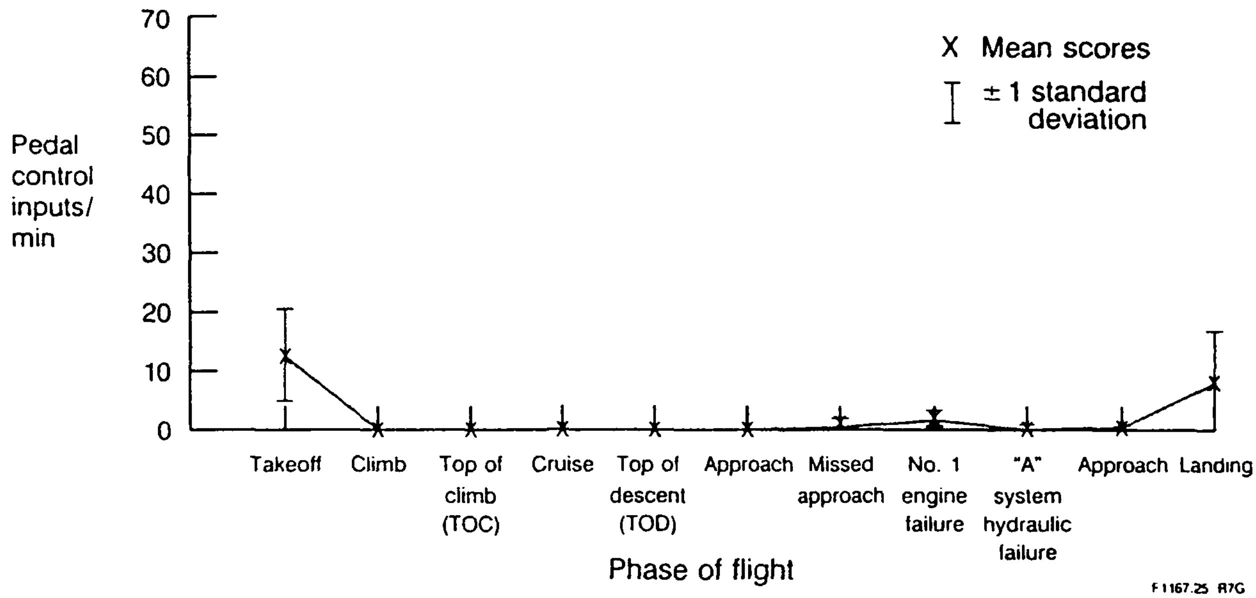


Figure 9.2.1.3-12

Pedal (Rudder) Control Inputs (per Minute)

Full Mission Simulation

All Flights

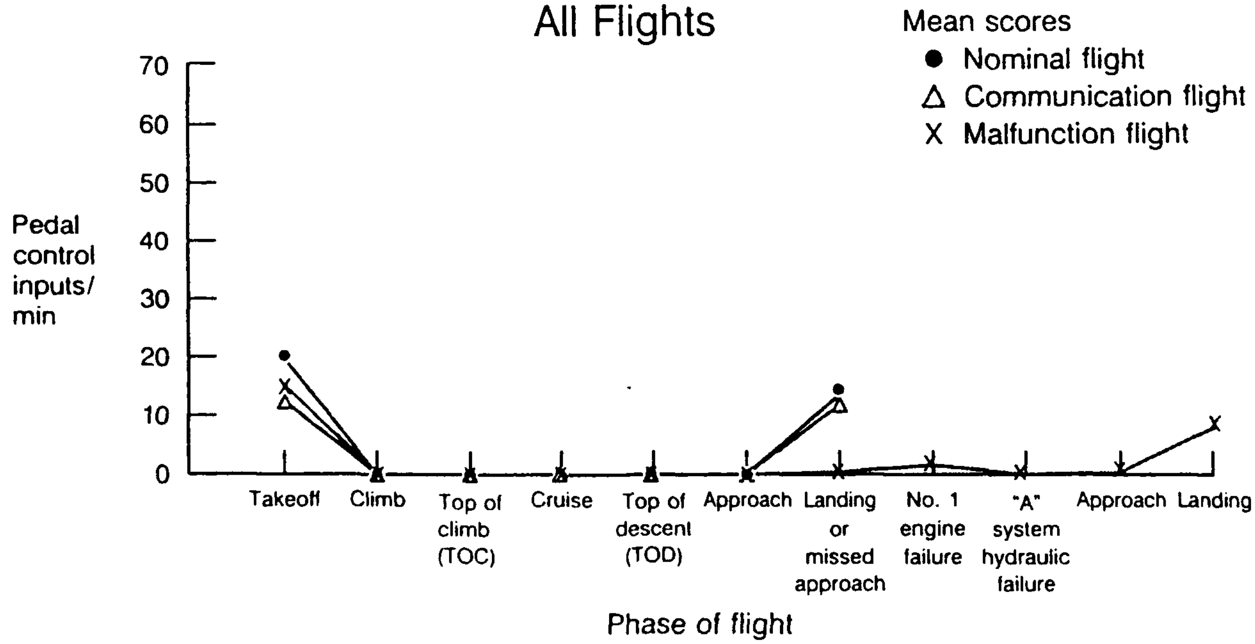


Table 9.2.1.3-5

Pedal (Rudder) Control Input

Full Mission Simulation Data
Means and Standard Deviations

Window	Nominal Mean	Nominal SD	Communication Mean	Communication SD	Malfunction Mean	Malfunction SD
Takeoff	19.70	(10.2)	15.20	(8.1)	13.50	(8.1)
Climb	0.10	(0.3)	0.00	(0.0)	0.00	(0.0)
Top of climb	0.03	(0.1)	0.00	(0.0)	0.00	(0.0)
Cruise	0.00	(0.0)	0.00	(0.0)	0.00	(0.0)
Top of descent	0.00	(0.0)	0.03	(0.1)	0.03	(0.1)
Approach	0.10	(0.4)	0.20	(0.2)	0.10	(0.4)
Landing or M/A	13.70	(12.9)	11.90	(10.2)	1.60	(5.0)
No. 1 engine failure					2.20	(2.6)
"A" hydraulic failure					0.05	(0.1)
Approach					0.80	(1.7)
Landing					11.30	(16.0)

H1167.14 H3cb

Table 9.2.1.3-6

Pedal (Rudder) Control Inputs

Full Mission Simulation
Test-Retest
Reliability Correlations

Window	Nominal flight	Communication flight	Malfunction flight
Takeoff	0.57	0.42	0.59
Climb	0	0	0
Top of climb	0	0	0
Cruise	0	0	0
Top of descent	0	0	0
Approach	0.73*	0	1.0*
Landing or missed approach	0.66*	-0.26	0.77*
No. 1 engine failure			0.84*
"A" system hydraulics failure			-0.10
Approach			0.57
Landing			0.77*

r(14) = 0.623*
* Significant $p < 0.01$

H1167.09 H8G

Table 9.3-1

Correlation Matrix

Full Mission Simulation

	BEDF	ISWT	PSWT	WHL	STK	PDL	HRM	HRSD	ABP	ARS	EBK
BEDF	1.00										
ISWT	**0.92**	1.00									
PSWT	**0.98**	**0.94**	1.00								
WHL	0.44	**0.69**	**0.51**	1.00							
STK	0.36	**0.61**	0.46	**0.93**	1.00						
PDL	0.12	0.32	0.20	0.41	**0.55**	1.00					
HRM	**-0.68**	**-0.82**	**-0.75**	**-0.82**	**-0.85**	-0.50	1.00				
HRSD	0.25	0.29	0.22	0.47	0.37	-0.23	-0.22	1.00			
ABP	-0.24	-0.50	-0.35	**-0.69**	**-0.75**	**-0.64**	**0.70**	0.18	1.00		
ARS	0.02	-0.14	-0.10	-0.41	**-0.60**	**-0.54**	**0.59**	0.22	**0.68**	1.00	
EBK	-0.20	-0.17	-0.23	-0.16	-0.10	0.29	0.23	0.15	0.29	0.07	1.00

Variable Labels

BEDF	Bedford rating scale
ISWT	Inflight SWAT ratings
PSWT	Postflight SWAT ratings
WHL	Wheel control input (aileron) per minute
STK	Column control input (elevator) per minute
PDL	Pedal control input (rudder) per minute
HRM	Average Interbeat Interval
HRSD	Standard Deviation for Average Interbeat Interval
ABP	Power Spectal Analysis B.P. component
ARS	Power Spectral Analysis Respiration component
EBK	Eye blinks per minute

Critical correlation values are r(23) = 0.505 or r(23) = -0.505 are in **bold**

H1167.01 R1rs

Table 9.4-1

Principal Component Analysis

Full Mission Simulation

Sorted rotated factor loadings (pattern)

	Factor 1	Factor 2	Factor 3	Factor 4
Blood pressure	0.893			
Respiration	0.867			
Column control input	-0.814	-0.306	0.461	
Pedal control input	-0.742			0.502
Average IBI	0.690	-0.634		
Wheel control input	-0.680	0.383	0.568	
Bedford		0.988		
Postflight SWAT		0.972		
Inflight SWAT	-0.301	0.918		
IBI variability			0.955	
Eye blink				0.956
VP	3.842	3.545	1.639	1.232

The above factor loading matrix has been rearranged so that the columns appear in decreasing order of variance explained by the factors. The rows have been rearranged so that for each successive factor, loadings greater than 0.500 appear first. Loadings less than 0.25 have been blanked.

H1167.

Our interpretation of the common underlying factors can be summarized as follows:

(a) Measures thought to reflect physical workload load highest on Factor 1 in the PCA,
(b) Measures reflecting mental workload load highest on Factor 2. Factors 3 and 4 do not account for much of the variance in the PCA,
(c) It should be noted that Wheel and Column control inputs load on Factor 3 in addition to Heart Rate Variability.

9.5 DISCUSSION

In addition to the criteria of validity and reliability, this contract effort has used replication in order to further give confidence to the interpretation of the results. The Full-Mission simulation utilized the lessons learned from the Part-Task simulation in order to once again subject the candidate workload measures to rigorous empirical scrutiny.

As was done with the Part-Task simulation, summaries of the results for the workload measures are provided. The first table summarizes the empirical findings of validity and reliability (Table 9.5-1). The second table presents the rank ordering of the phases of flight for each workload measure (Table 9.5-2).

9.5.1 DISCUSSION OF VALIDITY AND RELIABILITY RESULTS

To summarize the results of two comprehensive simulation studies in a few pages is difficult. Volume I was written with the intent of providing as much of the empirical results from the simulation studies as possible. It is an overwhelming task to attempt to integrate the results in a manner that would state a clear "winner" as to which is the best workload measure available. Again, we suggest that the reader examine the results for the studies one workload measure at a time. The studies were designed in such a fashion that the measures could be considered as if it were the only dependent variable in the simulation effort. In this fashion a reader can evaluate a given workload measure for validity and reliability, and determine if the results were replicated from the Part-Task to Full-Mission simulation.

<u>SUBJECTIVE</u>

The Full-Mission simulation examined SWAT both In-Flight and Post-Flight to determine if there was a difference for probe timing. Although no main effect of probe timing was found (In-Flight versus Post-Flight) a significant interaction of probe timing and workload flight (Nominal, Communication, and Malfunction) was found. The overall look to the probe timing difference is that In-Flight ratings tend to be lower than Post-Flight ratings until there are periods of high workload (malfunctions for example) then the trend reverses. The reader is directed to a paper by Corwin (1989) for a more detailed discussion of the In-Flight versus Post-Flight results from the Full-Mission simulation.

Both SWAT (In-Flight and Post-Flight) and the Bedford rating scale demonstrated evidence of validity and reliability. The Bedford scale was the first time a single, uni-dimensional, scale had been used in isolation in either of the simulation studies. (The 1-to-20 point Overall Workload Scale was used in conjunction with the NASA-Task Load Index in the Part-Task simulation.)

The Bedford rating scale, similar to the Modified Cooper-Harper or McDonnell Workload scale, requires no data reduction as do SWAT or the NASA-TLX. The elimination of the overhead associated with the "customization" of either SWAT or the NASA-TLX makes

Table 9.5-1

FULL-MISSION SIMULATION	SUBJECTIVE			PHYSIOLOGICAL					PERFORMANCE		
	SWAT-I	SWAT-P	BDFD	EB	HR	HRV	SBP	SRS	WHEEL	COLUMN	PEDAL
VALIDITY											
WORKLOAD DISCRIMINATION Flight Main Effect ANOVA	NO	YES	YES	NO	NO	NO	NO	NO	YES	YES	YES
PAIR-WISE FLIGHT COMPARISON (3 possible) ANOVA	2	3	3	1	0	0	0	0	2	2	2
PHASE OF FLIGHT DISCRIMINATION Nominal ANOVA	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
INDIVIDUAL PHASE OF FLIGHT COMPARISONS (21 possible) Newman-Kuels	9	7	11	0	6	0	2	0	10	10	11
PHASE OF FLIGHT DISCRIMINATION Communication ANOVA	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES
INDIVIDUAL PHASE OF FLIGHT COMPARISONS (21 possible) Newman-Kuels	6	7	6	0	11	1	6	0	8	10	10
PHASE OF FLIGHT DISCRIMINATION Malfunction ANOVA	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
INDIVIDUAL PHASE OF FLIGHT COMPARISONS (55 possible) Newman-Kuels	30	33	35	11	23	3	13	3	35	22	18
RELIABILITY											
NOMINAL FLIGHT Test-Retest Correlation Day 1 to Day 2 (7 possible)	1	2	2	4	7	0	0	0	3	0	2
COMMUNICATION FLIGHT Test-Retest Correlations Day 1 to Day 2 (7 possible)	3	3	1	4	7	0	2	0	2	0	0
MALFUNCTION FLIGHT Test-Retest Correlations Day 1 to Day 2 (11 possible)	4	5	2	6	11	1	3	0	5	3	3
INTER-RATER AGREEMENT Each Pilot to Group Average	94%	94%	94%	56%	78%	44%	17%	28%	100%	100%	100%

SWAT - SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE
I - IN FLIGHT
P - POST FLIGHT
BDFD - BEDFORD RATING SCALE

EB - EYEBLINK RATE (BLINKS PER MINUTE)
HR - HEART RATE IN INTERBEAT INTERVAL (IBI)
HRV - STANDARD DEVIATION OF IBI
SBP - POWER SPECTRAL ANALYSIS (BLOOD PRES. COMPONENT)
SRS - POWER SPECTRAL ANALYSIS- (RESPIRATION COMPONENT)

WHEEL- WHEEL CONTROL INPUT (PER MINUTE)
COLUMN- COLUMN CONTROL INPUT (PER MINUTE)
PEDAL- PEDAL CONTROL INPUT (PER MINUTE)

Table 9.5-2

Full-Mission Simulation (Rank Order of Phase of Flight)

NOMINAL WORKLOAD FLIGHT

PHASE OF FLIGHT	IN-SWAT	POST-SWAT	BEDFORD	EYEBLINK	IBI	IBI SD	BLOOD PRES.	RESPIRATION	WHEEL	COLUMN	PEDAL
Takeoff	6	6	7	2	6	1	6	6	4	6	7
Climb	3	3	3	5.5	1.5	3	5	3	6	3	4.5
Top of Climb	2	2	2	3.5	4	4	1	4	3	4	3
Cruise	1	1	1	1	1.5	6	2	5	1	1	1.5
Top of Descent	5	5	4.5	7	3	2	4	1	2	2	1.5
Approach	4	4	4.5	5.5	5	7	3	2	5	5	4.5
Landing	7	7	6	3.5	7	5	7	7	7	7	6

COMMUNICATION WORKLOAD FLIGHT

PHASE OF FLIGHT	IN-SWAT	POST-SWAT	BEDFORD	EYEBLINK	IBI	IBI SD	BLOOD PRES.	RESPIRATION	WHEEL	COLUMN	PEDAL
Takeoff	6	6	7	1.5	6	1	6	6	3.5	6	7
Climb	5	3	3	4	2	2	5	5	3.5	3	2
Top of Climb	2	1	1.5	7	1	4	1	3	5	4	2
Cruise	1	2	1.5	1.5	4	6	2	4	1	2	2
Top of Descent	3	4	4	5	3	5	4	2	2	1	4
Approach	4	5	5	6	5	3	3	1	6	5	5
Landing	7	7	6	3	7	7	7	7	7	7	6

MALFUNCTION WORKLOAD FLIGHT

PHASE OF FLIGHT	IN-SWAT	POST-SWAT	BEDFORD	EYEBLINK	IBI	IBI SD	BLOOD PRES.	RESPIRATION	WHEEL	COLUMN	PEDAL
Takeoff	5	3	3	2	6	1	9	9.5	3	6	11
Climb	4	2	2	9	4.5	6	6	4.5	6	4	2
Top of Climb	1	1	1	7	1	4	5	7	2	3	2
Cruise	3	5	4.5	3	2	8	3	2.5	1	1.5	2
Top of Descent	2	4	4.5	6	3	3	2	7	4	1.5	4
Approach	6	7	8	10	7	2	7.5	1	7	8	6
Missed Approach	10	11	10	11	11	5	10	11	10	10	8
#1 Engine Failure	11	10	11	8	9	9	4	9.5	9	9	9
A" System Hyd. Failure	8	9	9	1	4.5	10	1	4.5	5	5	5
Approach	7	6	8	5	8	7	7.5	7	8	7	7
Landing	9	8	8	4	10	11	11	2.5	11	11	10

the interpretation of the data a much more straight forward exercise. The dividend of the subjective techniques based on multiple bipolar ratings (SWAT & the NASA-TLX) is the ability to examine the underlying causes of workload fluctuation by examining the individual bipolar ratings. The examination of the underlying influences on workload may or may not be better addressed in a aircraft certification effort by the Pilot Subjective Evaluation (PSE) technique (Fadden, 1982; Ruggiero and Fadden, 1987). No empirical evidence exists comparing PSE with SWAT or the NASA-TLX. Yet, the PSE directly addresses the Functions and Factors of FAR 25.1523 Appendix D, while both SWAT and the NASA-TLX address generic underlying factors.

PHYSIOLOGICAL

Eyeblink rate was found to be a reliable measure, but could not discriminate among the various workload conditions. Again the reader is reminded of the different visual tasks required for piloting a commercial transport aircraft, some which may cause a decrease in eyeblink rate while others cause an increase. This may be the reason discriminability of the workload conditions was not found. Eyeblink rate may be of more utility in examining workload in aircraft environments that do not require as much reading and head turning to scan system instruments, such as tactical fighter aircraft.

Mean Heart Rate again demonstrated phenomenal reliability: all 25 test/retest correlation coefficients were significant. Unfortunately mean Heart Rate could not discriminate among the three workload flights (Nominal, Communication, and Malfunction). The lack of discriminability was surprising. In an attempt to understand the lack of discriminability Post Hoc a careful examination was made of the changes in Heart Rate within the measurement windows (Metalis et. al., 1989). It appears that Heart Rate, whether influenced by arousal and/or workload, is extremely sensitive to shifts in task demands in an acute fashion. That is, the phasic changes associated with Heart Rate occur quite quickly then return to a baseline quickly. The interesting point to note is the length of the measurement period is important when considering workload. A measurement window which is long may have changes in Heart Rate due to increases in task demands mixed together with periods of rather low workload (low task demands).

Heart Rate Variability again demonstrated poor discriminability among the various workload conditions. Heart Rate Variability did not demonstrate evidence of reliability either.

The Blood Pressure and Respiration components of the Power Spectral Analysis did not demonstrate discriminability in the Full-Mission simulation. The Blood Pressure component did however demonstrate reliability, but a reliable measure that cannot discriminate among different workload levels does not have much utility.

The anomalous findings for the Respiration component in the Part-Task simulation, increase in the Respiration component with increasing workload, was not replicated in the Full-Mission simulation.

PERFORMANCE

Since both workload measures which accompany the Secondary Task were abandoned, only the control input activity measures were examined in the Full-Mission simulation.

As was demonstrated in the Part-Task simulation, control input activity for the Wheel and Column demonstrated both validity and reliability. As was seen in the Part-Task simulation Pedal activity is extremely low when maneuvering at altitude. Even with the low values for some of the phases of flight Pedal activity could discriminate between workload flights (Nominal, Communication, and Malfunction). The low values in some measurement windows had a detrimental influence on the reliability coefficients for those phases of flight.

9.5.2 DISCUSSION OF CORRELATION MATRIX

The most notable relationship change from the Part-Task to the Full-Mission simulations is the significant correlation of Heart Rate (IBI) to most of the other measures (SWAT in-flight & post-flight, Bedford, Wheel & Stick control inputs, and both the components from the power spectral analysis: Blood Pressure & Respiration).

The three subjective rating methods are highly inter-correlated. An interesting finding is that the highest correlation is among the two post-flight measures SWAT (post-flight) and Bedford ($r=0.98$). The correlation of SWAT in-flight and post-flight is smaller ($r=0.94$) than the correlation between the two post-flight measures.

The anomaly of a positive correlation of the respiration component (power spectral analysis) to other workload measures in the Part-Task simulation was not replicated in the Full-Mission simulation.

9.6 GENERAL DISCUSSION

The contract effort has attempted to identify suitable workload assessment techniques for aircraft certification by reviewing the literature (Fact Matrices), find consensus among experts (two Workshops), and empirical testing (two simulation studies).

> The experiments we do today, if successful, will need replication and cross-validation at other times under other conditions before they can become an established part of science, before they can be theoretically interpreted with confidence. (Campbell and Stanley, 1963)

The empirical requirements for sound research put forth by Campbell and Stanley have been complied with in the simulation tests conducted as part of this contract. A test/retest methodology was employed in the simulation tests to determine the reliability of each measure under identical test conditions. In order to replicate and cross-validate the results two simulation tests were conducted. The second simulation test included more severe workload manipulations (e.g., Missed Approach; "A," as opposed to "B," hydraulics system failure; enroute diversion), as well as simply replicating the conditions of the first simulation test.

Again, it should be mentioned that the area of workload assessment is a developing science. Subjective ratings (SWAT, NASA-TLX, Bedford, 1-to-20 Workload score), Heart Rate (interbeat interval), and Control Input Activity all demonstrated evidence of validity and reliability in the simulation studies conducted at NASA-Ames. Today's results will likely become obsolete as newer methods are developed, but the measures identified can, and should, be used to help answer the questions of the amount of workload imposed on flightcrews.

10.0 CONTENTS OF VOLUME TWO

Perhaps the most important product of this contract is Volume Two of the Final Report. A series of guidelines were developed to aid in the evaluation of workload assessment certification programs for commercial transport aircraft.

The guidelines were complied based on the data and experience obtained in this research contract from the literature review, part-task simulation testing, full-mission simulation testing, and the two workshops, These guidelines include:

(a) Evaluation criteria for assessment techniques,
(b) Workload assessment techniques guidelines,
(c) Guidelines for task scenario development.

It is the purpose of Volume II of the final report to present specific guidelines and recommendations for evaluating workload certification plans. No attempt is being made to provide a "cookbook" for the generation of an aircraft workload certification plan. An emphasis is placed upon the transient nature of workload assessment. In a few years, many of the current state-of-the art workload measures may become obsolete. The contents of Volume II are designed to allow for the evaluation of current, and yet to be developed, workload assessment techniques.

Volume Two contains guidelines and recommendations for evaluating the validity, reliability, and applicability of proposed workload certification plans. The specific areas addressed for evaluation criteria include:

(a) Validity,
(b) Reliability,
(c) Applicability.

The workload assessment techniques are broken down by domain area:

(a) Subjective,
(b) Performance,
(c) Physiological,
(d) Analytical.

Advantages and liabilities of the techniques employed in the simulation studies (as reported in Volume One) are discussed. Previous work reported by others using the various assessment techniques is documented for the reader as well. Additionally, data derived evidence is given for the recommendation of specific valid, reliable, and applicable workload measures.

Finally, the process of evaluating the scenario description is itemized:

(a) Scenario Description
(b) Scenario Evaluation Criteria
(c) Relation of Workload to FAR Requirements

Since most aircraft are compared to some "baseline" aircraft in workload certification, the level of scenario description is important in order to establish a common ground for comparison.

11.0 RECOMMENDATIONS FOR FUTURE WORK

The present work does not presume to have put forth the definitive empirical investigation of workload. What the present work has accomplished is a rigorous testing of the validity and reliability of existing workload measures in a commercial transport aircraft environment. It is hoped that this work will serve as a reference to personnel who must evaluate the adequacy of candidate workload measures in certification plans for FAR 25 type approval.

Follow-on research should identify the points (minimum and maximum) for each measure where crew performance breaks down. Peak workloads have attracted a fair amount of attention due to ever increasing demands being imposed on flight crews. Current design practices, however, have resulted in reduced crew workload in virtually every segment of flight. Currently there is a need to explore low workload. In commercial aviation, underload (long periods of low task-demands) should be further explored to identify the affect it can have on crew performance. If the crew habituates to a lower task demands (experiences a reduction of available capacity) due to underload, moderate levels of task difficulty can suddenly be experienced as high workload.

Another pressing issue is to develop a technique which will allow the results of workload assessment from different pilots to be evaluated on a common scale. The development of an "absolute" workload scale may not be so much a question of workload methodology as it is psychometrics.

Finally, the influence of workload on performance needs to be addressed in a definitive fashion. Intuitively it is easy to understand how periods of high workload can cause performance to drop off. The subtle influence of workload on performance and error rate is perhaps the behavioral link which stimulates the interest in workload in an aviation environment.

REFERENCES

Anastasi, A. (1968), Psychological Testing (3rd ed.) London: Macmillan.

Battiste, V., and Bortolussi, M. (1988), "Transport Pilot Workload: A Comparison of Two Subjective Techniques," Proceedings of the Thirty-Second Annual Meeting of the Human Factors Society, 150-154.

Biferno, M. A., and Boucek, G. P. (1987a), "Proceedings of the Workshop on the Assessment of Crew Workload Measurement Methods, Techniques and Procedures: Volume I - Preliminary Selection of Measures," Report No. AFWAL-TR-87-3043, Vol I. Wright-Patterson Air Force Base, Ohio: USAF Flight Dynamics Laboratory.

Biferno, M. A., and Boucek, G. P. (1987b), "Proceedings of the Workshop on the Assessment of Crew Workload Measurement Methods, Techniques and Procedures: Volume II - Library References," Report No. AFWAL-TR-87-3043, Vol II. Wright-Patterson Air Force Base, Ohio: USAF Flight Dynamics Laboratory.

Boucek, G. P., Sandry-Garza, D. L., Logan, A. L., Biferno, M. A., Corwin, W. H., and Metalis, S. A., (1987), "Proceedings of the Workshop on the Assessment of Crew Workload Measurement Methods, Techniques and Procedures: Part-Task Data Summary," Report No. AFWAL-TR-87-3103. Wright-Patterson Air Force Base, Ohio: USAF Flight Dynamics Laboratory.

Campbell, D. T., and Stanley, J. C. (1963), Experimental and Quasi-Experimental Designs for Research. Rand McNally & Company: Chicago, IL.

Cooper, G. E., and Harper, R. P., Jr. (1969), "The Use of Pilot Ratings in the Evaluation of Aircraft Handling Qualities," NASA TN D-5153. Moffett Field, CA: NASA Ames Research Center.

Corwin, W. H. (1989), "In-Flight and Post-Flight Assessment of Pilot Workload in Commercial Transport Aircraft Using SWAT," Proceedings of the Fifth International Aviation Psychology Symposium. Columbus, Ohio.

Corwin, W. H., Sandry-Garza, D. L., Biferno, M. A., and Boucek, G. P. (1989) "Guidelines for the Use of Workload Assessment Techniques in Aircraft Certification," Report No. AFWAL-TR-89-7006. Wright-Patterson Air Force Base, Ohio: USAF Flight Dynamics Laboratory.

Fadden, D. M. (1982), "Boeing Model 767 Flight Deck Workload Assessment Methodology," Paper presented at the SAE Guidance and Control System Meeting, Williamsburg, VA.

Kirk, R. E. (1982), Experimental Design: Procedures for the Behavioral Sciences. Monterey: Brooks/Cole.

McLucas, J. L., Drinkwater, F. J., and Leaf, H. W. (1981), "Report of the President's Task Force on Aircraft Crew Complement," Prepared for the President, The White House, Washington D. C..

Metalis, S. A., Biferno, M. A., and Corwin, W. H. (1989), "Is Heart Rate a Valid, Reliable, and Applicable Index of Pilot Workload in Commercial Transport Aircraft?" Proceedings of the Fifth International Aviation Psychology Symposium. Columbus, Ohio.

Miller, K. M. (1976), "Timeline Analysis Program (TLA-1), final report," Boeing Document D6-42377-5, Prepared for National Aeronautics and Space Administration, Langley Research Center (NASA-CR-144942).

Mulder, G. (1979), "Sinus Arrythmia and Mental Workload," In (Ed. Moray, N.) Mental Workload: Its Theory and Measurement. Plenum Press, New York.

Orlady, H. W., (1982), "Flight Crew Performance When Pilot Flying and Pilot Not Flying Duties are Exchanged," (NAS2-10060, Contractor Report 166433), Ames Research Center: Moffett Field, CA.

Ruggiero, F. T., and Fadden, D. M. (1987), "Pilot Subjective Evaluation of Workload During a Flight Test Certification Program," Proceedings of the AGARD Conference on Methods to Assess Workload, (AGARD-CPP-282).

Vidulich, M., and Bortolussi, M. (1989), "A Dissociation of Objective and Subjective Workload Measures," Proceedings of the Thirty-Second Annual Meeting of the Human Factors Society, 1471-1476.

APPENDIX A

DISPATCH RELEASE PACKETS

DISPATCH RELEASE PACKETS

DISPATCH RELEASES

SFO-SCK

FLIGHT PATH

Takeoff SFO 28R
Quiet 9 Departure
REBAS Intersection
Direct Modesto VOR
Landing SCK 29R

WEATHER

SFO CLR 20 59/45 2505 995
SCK CLR 20 62/40 2910+15 990
SMF CLR 15 60/52 1905 998

ROUTE DATA

Distance 106 NM
Trip Fuel 5,600 lbs.
Altitude 11,000 ft.
ETE 0+27
Alternate SMF
Distance 57 NM
Fuel 2,500 lbs.
EIE 0+14

Holding (30 Min.)	3,700 lbs.
Total Fuel Req.	11,800 lbs.
Fuel on board	14,000 lbs.
Reserves	2,200 lbs.

WEIGHT & BALANCE

OEW	101,600 lbs.
Payload	23,400 lbs.
ZFW	125,000 lbs.
Fuel	14,000 lbs.
TOGW	139,000 lbs.
CG	24%
Est. LGW	133,400 lbs.

NOTAMS

SCK RWY 29I Closed

MEL

Autopilot Inop.

SMF-SFO

FLIGHT PATH

Takeoff SMF 16
Direct SAC VOR
Risti 2 departure
CEDES Intersection
Landing SFO 28L

WEATHER

SMF CLR 15 60/52 1905 998
SFO CLR 20 59/45 2505 995
OAK CLR 10H 58/48 CLM 990

ROUTE DATA

Distance 96 NM
Trip Fuel 5,500 lbs.
Altitude 11,000 ft.
ETE 0+25
Alternate OAK
Distance 27 NM
Fuel 1,800 lbs.

WEIGHT & BALANCE

OEW	101,600 lbs.
Payload	23,400 lbs.
ZFW	125,000 lbs.
Fuel	14,000 lbs.
TOGW	139,000 lbs.
CG	24%
Est. LGW	133,500 lbs.

ETE 0+10	
Holding (30 Min.)	3,700 lbs.
Total Fuel Req.	11,000 lbs.
Fuel on board	14,000 lbs.
Reserves	3,000 lbs.

<u>NOTAMS</u>

None

<u>MEL</u>

Autopilot Inop.

LAX-(SFO)-(OAK)-SMF

<u>FLIGHT PATH</u>

Takeoff LAX 25R
Ventura 9 Departure
RZS Transition
J-501 BSR
BSR profile descent
SFO

<u>WEATHER</u>

LAX CLR 15 60/40 CLM 990
SFO CLR 20 59/45 2505 995
SMF CLR 15 60/52 1905 998

<u>ROUTE DATA</u>

Distance 290 NM
Trip Fuel 11,000 lbs.
Altitude FL310
ETE 0+55
Alternate SMF
Distance 85 NM
Fuel 4,500 lbs.
ETE 0+10

Holding (30 Min.)	3,700 lbs.
Total Fuel Req.	19,200 lbs.
Fuel on board	25,000 lbs.
Reserves	5,800 lbs.

<u>WEIGHT & BALANCE</u>

OEW	101,600 lbs.
Payload	23,400 lbs.
ZFW	125,000 lbs.
Fuel	25,000 lbs.
TOGW	150,000 lbs.
CG	21%
Est. LGW	139,000 lbs.

<u>NOTAMS</u>

None

<u>MEL</u>

Autopilot Inop.

APPENDIX B

FULL-MISSION SIMULATION EXAMPLE SCENARIO

FULL-MISSION SIMULATION EXAMPLE SCENARIO

FULL-MISSION SIMULATION: LONG LEG (HIGH WORKLOAD)
LAX TO SFO DIVERTED TO OAK DIVERTED TO SMF

UPDATE 10/02/87

SUNDAY, JANUARY 25, 1987 TWILIGHT

START LEG 1850

HH:MM:SS CAPTAIN

00:00:00 RECEIVES TAKEOFF CLEARANCE

*HEARS TOWER, "___103, CLEARED FOR TAKEOFF RUNWAY 24R.

00:00:15 TAKEOFF

*DEPRESSES TOPS OF RUDDER PEDALS WITH FEET.
*HEARS BRAKE LEVER RELEASE.
*SENSES AIRPLANE START TO ROLL.
*PLACES RIGHT HAND ON THRUST LEVERS.
*PLACES LEFT HAND ON OUTBOARD GRIP OF CONTROL WHEEL.
*ADVANCES THRUST LEVERS FOR INITIAL ACCELERATION AND ALLOWS EVEN ENGINE SPOOLUP.
*LOOKS AT EPR INDICATORS FOR EVEN ENGINE ACCELERATION.
*CONTINUES THRUST LEVERS TO APPROXIMATE TAKEOFF SETTING
*CHECK EPR INDICATORS FOR TAKEOFF BUG SETTING
*KEEPS RIGHT HAND ON THRUST LEVERS AS F/O ADJUSTS.
*LOOKS THROUGH LEFT FRONT WINDOW ALONG RUNWAY CENTERLINE.
*STEERS AIRPLANE ALONG RUNWAY CENTERLINE WITHRUDDER PEDALS.
*MAINTAINS LIGHT FORWARD PRESSURE ON COLUMN.
*KEEPS WINGS LEVEL.
*HEARS F/O, "80 KNOTS."
*LOOKS AT AIRSPEED DISPLAY.
*SAYS, "CHECK."
*CONTINUES LOOKING OUT FORWARD WINDOW.

00:00:38 ROTATION

*HEARS F/O, "V ONE."
*MOVES RIGHT HAND FROM THRUST LEVER TO

CONTROL WHEEL.
*HEARS F/O, "ROTATE."
*LOOKS AT AIRSPEED.
(SEES CORRELATION WITH F/O REPORT).
*BEGINS TO APPLY BACK FORCE ON CONTROL WHEEL.
*ROTATES TO LIFTOFF ATTITUDE.
*COMPLETE ROTATION TO DESIRED ATTITUDE WITH REFERENCE TO ATTITUDE INDICATOR.
*SENSES LIFT OFF.
*CHECKS ALTIMETER AND RATE OF CLIMB INDICATOR FOR POSITIVE RATE OF CLIMB.
*HEARS F/O, "V TWO."
*HEARS F/O, POSITIVE RATE OF CLIMB."
*CONFIRMS INCREASING ALTITUDE AND RATE OF CLIMB.

00:00:47 GEAR RETRACT - START INITIAL CLIMB

*CALLS, "GEAR UP."
*HEARS F/O, "GEAR UP."
*SEES F/O COMPLIANCE (PERIPHERAL VISION).
*LOOKS TO SEE IF AIRSPEED STABILIZED AT APPROXIMATELY V2 +10.
*ADJUSTS PITCH ATTITUDE TO MAINTAIN V2 +10 IF NECESSARY.

00:01:05 NOISE ABATEMENT CLIMB

*MAINTAINS V2 +10 KNOTS BY ADJUSTING PITCH ATTITUDE.

00:01:40 FLAPS 15

*SEES CLIMBING THROUGH 2500 FEET MSL.
*REDUCES AIRPLANE PITCH ATTITUDE TO MAINTAIN 500 TO 1000 FPM VERTICAL SPEED.
*SEES AIRSPEED INCREASING ABOVE V2 + 10
*CALLS, "FLAPS 5."
*HEARS F/O, "FLAPS 5."
*SETS AIRSPEED CURSOR TO 220 KNOTS.
*CONTINUES PITCH ADJUSTMENT TO MAINTAIN 500 TO 1000 FPM.
*SETS ELEVATOR TRIM.

00:01:50 FLAPS 5

*CHECKS FLAP INDICATOR AT 5.
*CHECKS AIRSPEED ABOVE 160 KNOTS ACCELERATING.
*CALLS, "FLAPS 2."
*HEARS F/O, "Fl APS 2."
*CONTINUES PITCH ADJUSTMENT TO MAINTAIN 500 TO 1000 FPM.

00:01:51 LEVEL AT 2500 FEET

*LEVELS AIRPLANE AT 2500 FEET USING ADI, ALTIMETER AND VERTICAL SPEED INDICATOR.
*ADJUSTS THRUST TO MAINTAIN REQUIRED AIRSPEED.
*SETS ELEVATOR TRIM.

00:02:12 FLAPS 2

*CHECKS FLAP INDICATOR AT 2.
*CHECKS AIRSPEED AT 190 AND ACCELERATING.
*CALLS, "FLAPS UP."
*CONTINUES PITCH ADJUSTMENT TO MAINTAIN 500 TO 1000 FPM.
*SETS ELEVATOR TRIM

00:02:26 PASSING LOS ANGELES VORTAC RADIAL 300.

*HEARS LAX TWR, "___103, CONTACT LAX DEPARTURE ON 125.2.
*SEES F/O RETUNE RADIO'
*HEARS F/E CALL DEPARTURE.
*HEARS LAX DEP, "___103, PROCEED DIRECT GORMAN, CLIMB TO FL310."
*HEARS F/O, "___103, DIRECT GORMAN, FL310.
*COMMANDS F/O, "TUNE GORMAN ON #1 NAV RADIO."
*STARTS RIGHT TURN AND SETS 322 ON COURSE SELECTOR.
*SEES AIRPLANE ROLL INTO A RIGHT TURN.

00:02:35 FLAPS UP

*CHECKS FLAP INDICATOR AT 0.
*CHECKS AIRSPEED AT 210 KNOTS AND ACCELERATING.
*CHECKS LEADING EDGE FLAPS TRANSIT (AMBER) LIGHT OUT PRIOR TO EXCEEDING 210 KNOTS.
*CHECKS FLAP INDICATOR AT UP.
*MOVES THROTTLES UNTIL 3 EPRS SHOW CORRECT SETTING FOR CLIMB POWER.
*HEARS F/O, "FLAPS UP."
*ADJUSTS PITCH ATTITUDE TO ACCELERATE TO 250 KNOTS.
*SETS ELEVATOR TRIM.

00:02:40 COMPLETES TURN

*SEES AIRPLANE ROLL OUT ON HEADING 322 DEG.

00:02:50 CUTBACK THRUST

*SEES AIRSPEED APPROACHING 250 KNOTS.
*INCREASES PITCH ATTITUDE SLIGHTLY TO MAINTAIN 250 KNOTS.
*SEES F/E ADJUSTING THRUST LEVERS.

00:03:40 AFTER TAKEOFF CHECKLIST

*CALLS "AFTER TAKEOFF CHECKLIST."
*HEARS F/E, "IGNITION, OFF".
*HEARS F/E, "NO SMOKING AND SEAT BELT, OFF."
*HEARS F/E, "ANTI-ICE CLOSED, GEAR UP AND OFF, FLAPS UP, NO LIGHTS."
*HEARS F/E, "AUTO PACK TRIP SWITCH, CUT OUT."
*HEARS F/E, "HYDRAULICS, PRESSURE AND QUANTITY NORMAL."
*HEARS F/E, "PRESSURIZATION, CHECKED AND SET".
*HEARS F/E, "AFTER TAKEOFF CHECKLIST COMPLETE."

00:04:40 CALLS DISPATCH

*TELLS F/O, "GIVE DISPATCH TIMES."
*PRESSES NO.1 VHF RECEIVER SWITCH ON.
*HEARS F/O, " ___ 103, SAN FRANCISCO, 103 PUSH BACK XXXX, OFF AT XXXX, ESTIMATE SAN FRANCISCO XXX
*PRESSES NO.1 VHF RECEIVER SWITCH OFF.

00:04:45 ENTERING ICING CONDITIONS

*OBSERVES AIRCRAFT APPROACHING CLOUDS.
*OBSERVES TAT BELOW 10 DEGREES C.
*TURNS ON ENGINE IGNITION AND DIRECTS F/O TURN ON ENGINE ANTI-ICE.
*OBSERVES EPR DROP ALL 3 ENGINES.
*OBSERVES STABLE ENGINE OPERATION.

00:04:48 WING ANTI-ICE ON

*OBSERVES AIRCRAFT ENTER CLOUDS.
*OBSERVES ICE BUILDUP ON WINDSHIELD WIPERS.
*CALLS, "WING ANTI-ICE ON."
*OBSERVES EPR DROP ALL THREE ENGINES.
*COMMANDS F/E TO RE-ACT CLIMB POWER

00:05:00 PASSING 10,000 FEET

*OBSERVES ALTIMETER PASSING 10,000 FEET.

00:05:20 OBSERVES WEATHER CONDITIONS

*OBSERVES CLIMBING ABOVE OVERCAST INTO AN AREA OF CLEAR AIR
*DIRECTS F/O TURN OFF ENGINE AND WING ANTI-ICE.
*DIRECTS F/E TO CHECK CLIMB POWER, TURNS OFF IGNITION SWITCHES

00:05:00 BLEED TRIP

*HEARS F/E, "CAPTAIN, I HAVE A BLEED TRIP

ON NUMBER 3. SWITCHING AIR SOURCE TO NUMBER 2."
*CAPT SAYS, "ROGER, LET IT COOL AND ATTEMPT A RESET. COMPLETE THE CHECKLIST."
*F/E ACKNOWLEDGES.

00:06:30 CLEARANCE TO FL 310

*HEARS DEPARTURE, "BOEING 727 CLEARED TO FL310 LOS ANGELES CENTER ON 125.2."
*HEARS F/O, "BOEING 727, CLIMBING TO FL310, LOS ANGELES ON 125.2."
*SEES F/O SET 31,000 IN ALTITUDE SELECT WINDOW
*OBSERVES F/O CHANGE FREQUENCY TO 125.2.

00:06:45 RESUMES CLIMB

*SETS AIRSPEED CURSOR TO 310 KNOTS.
*ADJUSTS PITCH ATTITUDE TO MAINTAIN 310 KNOT CLIMB.
*SETS ELEVATOR TRIM.

00:07:00 CONTACTS LOS ANGELES CENTER

*HEARS F/O, "LOS ANGELES CENTER, ___103 CLIMBING TO FL 310."
*HEARS LOS ANGELES CENTER, "___103, SQUAWK IDENT."
*HEARS LOS ANGELES CENTER, "___103, RADAR CONTACT, MAINTAIN FL 310 CONTACT CENTER ON 125.05 OUT OF 230.

00:08:00 TRANSITION LEVEL (18000 FEET)

*SEES APPROACHING 18,000 FEET.
*CALLS, "TRANSITION LEVEL, RESET 29.92."
*RESETS CAPTAIN'S ALTIMETER TO 29.92.
*SAYS, "ALTIMETER SET."
*HEARS F/O, "TRANSITION LEVEL, RESET 29.92."

00:12:00 CONTROL CENTER REPORT

*HEARS F/O, LOS ANGELES CENTER, ___103 OUT OF 230 FOR 310."
*HEARS CENTER, "___103, RADAR CONTACT, MAINTAIN 310.

00:12:25 SPEED REFERENCE CHANGE

*SEES MACH INDICATOR IS .78.
*USES MACH .78 AS SPEED REFERENCE FOR REMAINDER OF CLIMB.

00:15:00 CROSS GORMAN VORTAC

*SEES OUTBOUND COURSE IS 304 DEGREE TO BIG SUR
*SETS HEADING AND COURSE CURSORS ON HSI FOR NEW COURSE OF 304 DEGREES
*OBSERVES F/O SETTING BIG SUR 114.0 ON

NAV RADIO
*TURNS TO NEW COURSE OF 304 DEGREES
*SEES VOR/LOC LIGHT IS GREEN
*TELLS F/O, "SET EPR BUGS TO CRUISE EPR."
*RETARDS THRUST LEVERS SLIGHTLY.

00:17:00 ALTITUDE ALERT

*SEES ALTIMETER APPROACHING 30,000 FEET.
*HEARS ALTITUDE ALERT.
*HEARS F/O "1000 FEET TO LEVEL OFF."
*SEES ALTITUDE ALERT LIGHT ILLUMINATE.

00:18:00 LEVEL OFF AT FL 310

*SEES ALTITUDE ALERT LIGHT EXTINGUISH.
*LEVELS AIRPLANE AT 31,000 FEET USING ADI, ALTIMETER AND VERTICAL SPEED INDICATOR
*SEES MACH HAS INCREASED TO .01 ABOVE CRUISE MACH SCHEDULE.
*PULLS THROTTLES BACK SLIGHTLY.
*CALLS "SET CRUISE THRUST."
*SEES F/E ADJUSTING THRUST.
*SETS ELEVATOR TRIM.
*EXTRA ATTENTION MONITORING THAT ALTITUDE SPEED AND COURSE ARE STABILIZED.

00:23:20 OBSERVES DME

*OBSERVES DME SHOWING DISTANCE REMAINING TO BIG SUR VORTAC.
*MENTALLY CALCULATES MINUTES TO ARRIVAL OVER BIG SUR.
*REMOVES ENROUTE CHART FROM UNDER DEPARTURE PLATE.
*LOCATES BIG SUR VORTAC AND NOTES 309 DEGREE COURSE OUT OF BIG SUR TO EUGEN INTERSECTION.

00:24:00 "A" HYDRAULIC PUMP LOW PRESSURE LIGHT

*HEARS F/E, "I HAVE A LOW PRESSURE LIGHT ON NUMBER 1 A PUMP. PRESSURE AND QUANTITY ARE OK."
*CAPT SAYS, "ROGER, COMPLETE THE CHECKLIST."
*HEARS F/E, "PUMP SWITCH OFF. I'LL MONITOR PRESSURE AND QUANTITY."
*CAPTAIN ACKNOWLEDGES.

00:31:00 DIVERSION SUMMARY

*HEARS SELCAL ACTIVATE.
*HEARS F/O, " 103, ANSWERING SELCAL."
*HEARS DISPATCH, " 103, THIS IS SFO DISPATCH. SFO IS CLOSED DUE TO POWER FAILURE. REQUEST YOU DIVERT TO OAKLAND AND WE'LL BUS THE PASSENGERS TO SFO. YOUR

ALTERNATE REMAINS SMF. OAKLAND WEATHER IS 200 FT SCATTERED 400 FT OVERCAST, VISIBILITY ONE MILE IN FOG, TEMPERATURE 55, DEWPOINT 54, ALTIMETER 29.86.
*HEARS F/O, "UNDERSTAND, WE'LL DIVERT TO OAK."

00:33:00 REQUEST CLEARANCE TO OAKLAND

*CAPT ORDERS F/O TO REQUEST CLEARANCE TO OAKLAND.
*HEARS F/O, "OAKLAND CENTER, ___103, REQUESTING TO DIVERT TO OAK."
*HEARS OAK CTR, "___103, FROM OVER BIG SUR, CLEARED TO CONTINUE BIG SUR PROFILE DESCENT TO MENLO, EXPECT VECTORS TO THE LOCALIZER FOR 29R AT OAKLAND."
*HEARS F/O, "___103, FROM BIG SUR PROFILE DESCENT TO MENLO, VECTORS TO 29R.

00:34:00 CROSSING BIG SUR

*OBSERVES #1 VOR NEEDLE SWING CROSSING BIG SUR VOR.
*SETS COURSE OF 309 IN #1 COURSE WINDOW.
*STARTS LEFT TURN TO MAINTAIN COURSE OF 309 DEG.

00:34:35 ON 309 DEGREE COURSE

*OBSERVES AIRPLANE ON COURSE OF 309 DEG.
*LEVELS WINGS TO MAINTAIN COURSE.

00:36:00 TUNE OAKLAND VOR

*ORDERS F/O TO TUNE OAK VOR ON #1 VOR.
*SETS #1 COURSE WINDOW TO 331 DEG.
*NOTES DME DISTANCE TO CARME.

00:36:20 REVIEWS FLIGHT PLAN

*LOOKS AT BIG SUR PROFILE PLATE IN APPROACH CHART HOLDER.
*REVIEWS WAYPOINTS AND ALTITUDES.
*REVIEWS ROUTE DIAGRAM.
*RAISES STAR CHART AND LOOKS AT RWY 29 APPROACH CHART.
*REVIEWS RWY 29 APPROACH FREQUENCIES.
*LEAVES CHART UNDER STAR IN CHART HOLDER
*COMMANDS F/O TO TUNE OAK VOR.
*SETS 331 IN COURSE WINDOW.
*CHECKS DISTANCE AND ALTITUDE RESTRICTIONS ON DESCENT CHART.

00:36:50 ADVISES CABIN OF DESTINATION CHANGE

*ROTATES MICROPHONE SELECTOR TO SERVICE INTERPHONE POSITION.
*PRESSES ATTENDANT CALL SWITCH.
*HEARS FLIGHT ATTENDANT, "FORWARD".

*SAYS, "WE'RE DIVERTING TO OAKLAND DUE TO SAN FRANCISCO POWER FAILURE. ESTIMATE ARRIVAL IN OAKLAND AT ____."
*HEARS FLIGHT ATTENDANT, "OK, THANKS, I'LL SPREAD THE WORD."
*ROTATES MICROPHONE SELECTOR TO VHF2 POSITION.

00:37:00 PASSING CARME

*NOTES COURSE BAR CENTERED OVER CARME.
*TURNS RIGHT TO MAINTAIN COURSE OF 331 DEG.
*SETS HEADING BUG TO 331 DEG.
*NOTES COURSE AND HEADING AGREE.
*LEVELS WINGS TO MAINTAIN 331 DEG COURSE.

00:37:20 CHECKS OAK ATIS

*SELECTS JEPPESEN MANUAL FROM FLIGHT KIT.
*TURNS TO OAKLAND SECTION CHART AND AIRFIELD DIAGRAM FROM MANUAL.
*SEES OAKLAND ATIS FREQUENCY IS 128.5.
*PLACES CHARTS IN HOLDER BENEATH BIG SUR PROFILE DESCENT PLATE.
*REMOVES ILS RWY 29 APPROACH PLATES.
*PLACES CHARTS IN HOLDER BENEATH BIG SUR ARRIVAL PLATE.
*REPLACES MANUAL IN FLIGHT CASE.
*SETS 128.5 IN WINDOW OF NO. 1 VHF.
*PLACES VHF 1 SWITCH TO ON.
*ADJUSTS VOLUME ON NO. 1 VHF.
*ADVISES F/O "ATIS ON VHF 1."
*HEARS, "OAKLAND AIRPORT TERMINAL INFORMATION GOLF. ESTIMATED 200 FT SCATTERED, 400 FT OVERCAST, VISIBILITY ONE MILE IN FOG, WIND CALM, TEMPERATURE 55, DEWPOINT 54, ALTIMETER 29.86. DEPARTURES AND LANDINGS ON RUNWAY 29. INFORM CONTROLLER ON INITIAL CONTACT THAT YOU HAVE INFO GOLF."
*PLACES VHF 1 SWITCH TO OFF.

00:37:50 CONTROL CENTER CHANGE

*HEARS CENTER, "___ 103, CONTINUE WITH OAKLAND ON 125.2."
*HEARS F/O, "___ 103, OAKLAND ON 125.2."
*HEARS F/O, OAKLAND, ___ 103, FL310."
*HEARS OAKLAND CENTER, "___ 103, SQUAWK IDENT."
*HEARS OAKLAND CENTER, "___ 103, RADAR CONTACT, MAINTAIN FL 310.

00:38:00 ADVISES CABIN OF TOP DESCENT

*ROTATES MICROPHONE SELECTOR TO SERVICE INTERPHONE POSITION.
*PRESSES ATTENDANT CALL SWITCH.

*HEARS FLIGHT ATTENDANT, "FORWARD."
*SAYS, "STARTING DESCENT. ESTIMATING OAKLAND ----.
*ROTATES MICROPHONE SELECTOR TO VHF 2 POSITION.

00:38:30 STARTS DESCENT

*ADVISES F/O "TOP DESCENT."
*PULLS THRUST LEVERS BACK TO IDLE.
*ESTABLISHES DESCENT USING ADI, AIRSPEED AND VERTICAL SPEED INDICATORS.
*SETS ELEVATOR TRIM.
*INTENSIFIES INSTRUMENT SCAN PATTER.
*HEARS F/O, "OAKLAND CENTER, ___103, OUT OF FL 310."
*HEARS ___103, ROGER."

00:39:03 CHECKS DESCENT PERFORMANCE

*DECIDES TO USE .80M/320KIAS SPEED SCHEDULE DURING DESCENT.
*ADJUSTS PITCH ATTITUDE TO MAINTAIN .80M/320 KIAS.
*INCLUDES DME IN INSTRUMENT CROSS CHECK.

00:39:30 DESCENT/APPROACH BRIEFING

*REPLACES ARRIVAL CHART WITH ILS RWY 29 CHART IN CHART HOLDER.
*REVIEWS APPROACH CHART.
*SAYS, "DESCENT APPROACH BRIEFING."
*SAYS, "THIS IS A BIG SUR PROFILE, PRESENTLY CLEARED AS PER PROFILE DESCENT TO MENLO, AN ILS TO 29, 108.7 ILS FREQUENCY, INBOUND COURSE 293 DEG DECISION HEIGHT 205 MSL AND 200 RADAR ALTIMETER. MISSED APPROACH, CLIMB TO 500 FEET, THEN CLIMBING LEFT TURN TO 4000 FEET VIA 260 DEGREES HEADING OUTBOUND TO SAUSALITO VOR, RADIAL 110 TO SAUSALITO."
*SETS 200 FEET ON RADAR ALTIMETER.
*SAYS, "DECISION HEIGHT SET."
*HEARS F/O, "DECISION HEIGHT SET."

00:40:15 REVIEWS APPROACH DATA

*RECALLS DESTINATION ENVIRONMENTAL CONDITIONS FROM ATIS BROADCAST.
*LOOKS AT AIRFIELD DIAGRAM ON APPROACH CHART HOLDER.
*CHECKS RUNWAY LENGTH ON AIRFIELD DIAGRAM.
*CHECKS LANDING WEIGHT FROM TOTAL FUEL.
*CHECKS PRESENT VREF FOR FLAP POSITIONS.
*DECIDES ON LANDING FLAPS 30.
*TELLS F/O, "WE'LL USE FLAPS 30 FOR LANDING."

00:41:00 RECHECKS WEATHER

*NOTES LIGHT TURBULENCE HAS BEGUN.

*DECIDES MODERATE TURBULENCE IS POSSIBLE
*CALLS, "SEAT BELT AND START SWITCHES ON
*HEARS F/O, "SWITCHES ON".

00:42:00 TRANSITION LEVEL (18,000 FEET)

*SEES APPROACHING 18,000 FEET.
*CALLS, "TRANSITION LEVEL, RESET 29.86."
*SETS CAPTAIN ALTIMETER AT 29.86."
*SETS CAPTAIN ALTIMETER AT 29.86.
*HEARS F/O, "TRANSITION LEVEL, RESET 29.86."
*COMPARES F/O ALTIMETER WITH CAPTAIN ALTIMETER.
*SEES ALTIMETERS AGREE WITHIN 50 FEET.
*SEES FAILURE FLAG NOT IN VIEW ON CAPTAIN ALTIMETER.

00:42:40 SETS AIR SPEED BUGS

*RECEIVES BUG CARD FROM F/E.
*SETS IAS CURSOR AT VREF+5.
*SETS 1 BUG AT VREF +10
*SETS 1 BUG AT 200 K..

00:43:50 CROSS SKUNK INTERSECTION

*CALLS, "SKUNK INTERSECTION".
*SEES VOR/LOC LIGHT IS GREEN.

00:43:40 RECHECKS DESCENT PERFORMANCE

*LOOKS AT DME DISTANCE FROM OAKLAND VOR.
*LOOKS AT VERTICAL SPEED INDICATOR.
*DECIDES DESCENT PERFORMANCE IS PROBABLY SATISFACTORY.

00:45:00 LEVEL OFF AT 10,000 FEET AND CROSS BOLDR INTERSECTION

*SEES OAK DME 34 MILES.
*SEES ALTITUDE ALERT LIGHT EXTINGUISH.
*LEVELS AIRPLANE AT 10,000 FEET USING ALTIMETER AND VERTICAL SPEED INDICATOR.
*ADVANCES THRUST TO MAINTAIN 250 KNOTS.
*SETS ELEVATOR TRIM.
*CALLS, "LANDING LIGHTS ON."
*SEES F/O COMPLIANCE.
*CALLS, "BOLDR INTERSECTION".
*SEES 331 DEG COURSE CONTINUES TO MENLO INTERSECTION.

00:45:10 HAND OFF TO APPROACH CONTROL

*HEARS CENTER, "___ 103, 15 MILES FROM MENLO, CONTACT OAKLAND APPROACH 124.4."
*HEARS F/O, "___ 103, GOING TO 124.4.
*HEARS F/0, "OAKLAND APPROACH, THIS IS ___103, WITH YOU

AT 10,000."
*HEARS OAK APP, "___103, RADAR CONTACT, MAINTAIN 10,000."
*HEARS F/O, "___103, ROGER."

00:48:00 CROSS MENLO INTERSECTION

*SEES OAK DME 16 MILES.
*CALLS "MENLO INTERSECTION"
*FOLLOWS FD TO ROLL OUT ON 348 DEGREES.

00:48:15 CHANGES AND CHECKS APPROACH STATUS

*MOVES ILS RWY 29 APPROACH CHART TO TOP POSITION IN HOLDER.
*REVIEWS KEY ITEMS OF OAKLAND ILS RWY 29 APPROACH - FREQUENCIES, COURSE, MINIMUM SECTOR ALTITUDE, FIELD ELEVATION, INITIAL APPROACH ALTITUDE, OUTER MARKER CROSSING ALTITUDE, DECISION HEIGHT, MISSED APPROACH PROCEDURE.
*PLACES MARKER BEACON AUDIO SWITCH ON.
*PLACES MARKER SWITCH ON HIGH.
*NOTES NO MARKER AUDIO SIGNAL.

00:49:00 DESCENT CLEARANCE TO 5000

*HEARS APPROACH, "___103, DESCEND AND MAINTAIN 5000, FLY HEADING 010 TO INTERCEPT THE 29R LOCALIZER."
*HEARS F/O, "___103, OUT OF TEN FOR FIVE, 010 TO 29R LOCALIZER."
*SEES F/O SET 5,000 IN ALTITUDE SELECT WINDOW.

00:49:10 STARTS DESCENT TO 5000

*PULLS THRUST LEVERS BACK TO IDLE.
*ESTABLISHES DESCENT USING ADI, AIRSPEED AND VERTICAL SPEED INDICATORS.
*SETS ELEVATOR TRIM.

00:50:00 LEVEL AT 5000 FEET

*SEES ALTITUDE ALERT LIGHT EXTINGUISH
*LEVELS AIRPLANE AT 5000 FEET USING ADI, ALTIMETER AND VERTICAL SPEED INDICATOR
*OBSERVES DISTANCE TO OAKLAND VORTAC ON DME INDICATOR.

00:50:15 DESCENT APPROACH CHECKLIST

*CALLS, "DESCENT APPROACH CHECKLIST."
*HEARS F/E, "SEAT BELT, ON".
*HEARS F/E, "ANTI-ICE, CLOSED."
*HEARS F/E, "LANDING LIGHTS, ON".
*HEARS F/E, "ALTIMETERS, SET AND CROSS CHECKED".

*"RADAR ALTIMETER", F/O "CHECKED".
*"FLIGHT INSTRUMENTS, FDS, AND RADIOS", F/O "SET AND CROSS CHECKED".
*"GO-AROUND EPR AND VREF" F/O "BUGS SET".
*HEARS F/E, "FUEL, SET FOR LANDING."
*HEARS F/E, "HYDRAULICS, PRESSURE AND QUANTITIES NORMAL".
*HEARS F/E, "PRESSURIZATION AND COOLING DOORS", *SET".
*HEARS F/E, "CIRCUIT BREAKERS, CHECKED".
*HEARS F/E, "DESCENT APPROACH CHECKLIST COMPLETE."

00:51:00 DESCENT CLEARANCE TO 2500

*HEARS APPROACH, " ___ 103, DESCEND TO 2500."
*HEARS F/O, " ___ 103, OUT OF FIVE FOR 2500."
*TELLS F/O, "ALTITUDE SELECT 3000."
*SEES F/O COMPLIANCE.

00:52:00 TUNES ILS FOR APPROACH

*TELLS F/O, "TUNE THE ILS."
*SETS COURSE CURSOR ON 293 DEGREES.
*HEARS F/O, "YOU HAVE ILS IDENTIFIED."

00:52:10 REDUCES AIRSPEED

*ADJUSTS PITCH ATTITUDE.
*LETS AIRSPEED DROP TO 200.,
*SETS ELEVATOR TRIM.

00:52:15 ALTITUDE ALERT

*SEES APPROACHING 3500 FEET.
*HEARS ALTITUDE ALERT.
*HEARS F/O, "1000 FEET TO LEVEL OFF."
*SEES ALTITUDE ALERT LIGHT ILLUMINATE.

00:52:25 FLAPS 2

*CALLS, "FLAPS 2."
*HEARS F/O, "FLAPS 2."
*HEARS GEAR WARNING HORN.
*F/E PULLS HORN CUTOUT SWITCH.
*SETS ELEVATOR TRIM.
*SEES FLAP INDICATOR AT FLAPS 2 AND ANNUNCIATOR LIGHT GREEN.
*ADJUSTS PITCH ATTITUDE AND SLOWS AIRPLANE TO 190 KNOTS.

00:52:45 FLAPS 5

*SEES AIRSPEED IS AT 190 KNOTS.
*CALLS, "FLAPS 5."

*HEARS F/O, "FLAPS."
*SETS ELEVATOR TRIM.
*SEES FLAP INDICATOR AT FLAPS 5 AND ANNUNCIATON LIGHT GREEN.
*SLOWS AIRPLANE TO 160 KNOTS.

00:53:00 LEVEL OFF AT 2500 FEET

*SEES ALTITUDE ALERT LIGHT EXTINGUISH.
*LEVELS AIRPLANE AT 2500 FEET USING ADI, ALTIMETER AND VERTICAL SPEED INDICATOR.
*PLACES FD ALTITUDE HOLD SWITCH ON.
*ADVANCES THRUST TO MAINTAIN 150 KNOTS.
*SETS ELEVATOR TRIM.

00:53:15 FLAPS 15

*SEES AIRSPEED IS AT 160 KNOTS.
*CALLS, "FLAPS 15."
*HEARS F/O, "FLAPS 15."
*SETS ELEVATOR TRIM.
*SEES FLAP INDICATOR AT FLAPS 15 AND ANNUNCIATOR LIGHT GREEN.
*SLOWS AIRPLANE TO 150 KNOTS.

00:53:30 ILS APPROACH CLEARANCE

*HEARS APPROACH, "___103, CLEARED TO INTERCEPT LOCALIZER, MAINTAIN 2500 UNTIL ESTABLISHED INBOUND. CLEARED FOR ILS 29, CONTACT OAKLAND TOWER 127.2 AT THE MARKER.
*HEARS F/O, "___103, TOWER 127.2 AT THE MARKER.

00:54:00 LOCALIZER ALIVE

*HEARS F/O, "LOCALIZER ALIVE."
*SEES LOCALIZER MOVING TOWARD CENTER OF HSI SCALE.

00:54:05 STARTS TURN TO INTERCEPT LOCALIZER

*SETS HEADING CURSOR TO 293 DEGREES.

00:54:30 COMPLETES TURN

*SEES AIRPLANE ROLL OUT ON LOCALIZER.

00:55:00 LOCALIZER CAPTURE

*SEES HEADING APPROACHING 293 DEGREES.
*SEES FD ANNUNCIATORS AGREE.
*SEES AIRPLANE ROLLING OUT OF TURN.
*SEES LOCALIZER IN HSI IS CENTERED.
*SEES, FD VOR/LOC LIGHT GREEN, GLIDE SLOPE LIGHTS AMBER.

00:55:15 SETS MISSED APPROACH DATA

*REVIEWS MISSED APPROACH PROCEDURE ON APPROACH CHART.
*SETS HEADING CURSOR ON 260 DEGREES.
*TELLS F/O, "ALTITUDE SELECT 4000."
*HEARS F/O, "4000."

00:55:40 GLIDE SLOPE ALIVE

*HEARS F/O, "GLIDE SLOPE ALIVE."
*SEES GLIDE SLOPE MOVING TOWARD CENTER OF ADI AND HSI.
*CALLS, "GEAR DOWN."
*SEES F/O LOWER GEAR.
*NOTES LANDING GEAR LIGHTS 3 GREEN.
*SEES AIRPLANE IS ONE DOT BELOW GLIDESLOPE.
*CALLS, "FLAPS 25."
*NOTES F/O SET FLAPS.
*REDUCES AIRSPEED TO 140 KNOTS.
*TRIMS ELEVATOR.

00:56:00 GLIDE SLOPE CAPTURE

*SEES AIRPLANE IS ON GLIDESLOPE.
*CALLS, "FLAPS 30, LANDING CHECKLIST."
*HEARS F/E, "ANTI-SKID, 5 RELEASES."
*HEARS F/E, "IGNITION ON."
*HEARS F/E, "NO SMOKING, ON."
*HEARS F/E, "GEAR, DOWN, IN, 3 GREEN."
*HEARS F/E, "FLAPS 40, 40, GREEN LIGHT."
*HEARS F/E, "HYDRAULICS, OK."
*HEARS F/E, "LANDING CHECKLIST COMPLETE."
*CAPTAIN ACKNOWLEDGES.
*REDUCES AIRSPEED TO V REF + 30.
*TRIMS ELEVATOR.

00:57:30 EXECUTE MISSED APPROACH

*REACHES MINIMUMS. F/O REPORTS "NO RUNWAY".
*ADD POWER
*ROTATE
*CALLS FOR FLAPS 25
*NOTES POSITIVE CLIMB RATE
*CALLS FOR GEAR UP

00:59:35 ENGINE OUT

*F/E REPORTS, "NO. 3 ENGINE FLAMED OUT".
*CAPT ACKNOWLEDGES
*CAPT ADDS RIGHT RUDDER
*CAPT CALLS, "ENGINE FAILURE/SHUTDOWN CHECKLIST
*CAPT TRIMS RUDDER AND STABILIZER
*HEARS F/O, "ESSENTIAL POWER ON OPERATING

GENERATOR."
*CAPT DIRECTS F/O TO DECLARE AN EMERGENCY
*F/O DECLARES EMERGENCY AND REQUESTS RADAR VECTOR DIRECT TO SMF

01:00:00 PASSING 500 FEET

*CAPT OBSERVES ALTIMETER PASSING 500 FEET
*INITIATES CLIMBING LEFT TURN TO 260 DEG HEADING TOWARD 4000 FEET DIRECT TO SAUSALITO.

01:00:30 ENGINE FAILURE/SHUTDOWN CHECKLIST

*F/E CALLS, "THRUST LEVER NO. 3, CLOSE"
*CAPT ACKNOWLEDGES AND CLOSES THRUST LEVER
*F/E CALLS, "START LEVER, CUTOFF"
*CAPT ACKNOWLEDGES AND CLOSES START LEVER.
*F/E CALLS, "GALLEY POWER, OFF".
*F/E CALLS, "CARGO OUTFLOW VALVE, CLOSED".
*F/E CALLS, "PACK SWITCH, OFF".
*F/E CALLS, "GENERATOR BREAKER LIGHT, ON".
*F/E CALLS, "ELECTRICAL LOAD, MONITORED".
*F/E CALLS, "FUEL SHUTOFF SWITCH, CLOSED".
*F/E CALLS, "ENGINE BLEED SWITCH, CLOSED".
*F/E CALLS, "WING AND ENGINE ANTI-ICE, NOT REQUIRED".
*F/E CALLS, "ONE GENERATOR INOP CHECKLIST IS COMPLETED; ENGINE FAILURE CHECKLIST COMPLETE".
*CAPT ACKNOWLEDGES

01:00:50 NO RESTART ATTEMPTED

*F/E INFORMS CAPTAIN THAT A RESTART SHOULD NOT BE ATTEMPTED DUE TO NO N1 COMPRESSOR ROTATION.
*CAPT ACKNOWLEDGES.

01:01:00 FLAP RETRACTION AND CLEANUP

*CAPT OBSERVES AIRSPEED AT V2+10.
*CAPT CALLS, "FLAPS 15".
*ACCELERATES TO 150
*ORDERS F/O TO TUNE SAUSALITO VORTAC.
*CAPT OBSERVES FLAPS 15 AND 150 KNOTS
*CAPT CALLS, "FLAPS 5".
*ACCELERATES TO 160.
*CAPT OBSERVES AIRSPEED 160.
*CAPT CALLS, "FLAPS 2".
*ACCELERATES TO 190.
*OBSERVES AIRSPEED 190 KNOTS.
*CAPT CALLS, "FLAPS UP".
*ACCELERATES TO 200.
*CAPT ADJUSTS PITCH, TRIM AND STABILIZER.

01:01:30 LEVEL 4000 FEET, FLAP RETRACTION COMPLETE

*SEES ALTITUDE ALERT LIGHT EXTINGUISH
*LEVELS AIRPLANE AT 4000 FEET USING ADI, ALTIMETER AND VERTICAL SPEED INDICATOR.
*HEARS F/O, "FLAPS UP".

01:03:00 INTERCEPT 110 DEGREE COURSE SAUSALITO VORTAC

*SEES OUTBOUND HEADING FROM SAUSALITO VORTAC IS 290 DEG."
*SETS HEADING AND COURSE CURSORS ON HSI FOR NEW COURSE OF 290 DEGREE.

01:03:45 REQUESTS EMERGENCY DIVERT TO SACRAMENTO METRO

*CALLS OAKLAND CENTER, "___103 ON MISSED APPROACH FROM OAKLAND, ENGINE OUT, REQUESTING EMERGENCY DIVERT TO SACRAMENTO". REQUEST 7000 FEET.
*HEARS CENTER, "___103, SMF REPORTING CLEAR AND 15, WHEN PASSING 4000 FEET TURN RIGHT 035 DEGREES AND PROCEED DIRECT SACRAMENTO. MAINTAIN 7000."
*HEARS F/O, "___103, ROGER, RIGHT 035 AT 4000, DIRECT SACRAMENTO, 7000."

01:05:45 *ORDERS F/O TO ADVISE DISPATCH OF DIVERSION TO SMF.

01:06:30 ALTITUDE WARNING

*HEARS ALTITUDE WARNING.
*HEARS F/O, "1000 FT TO LEVEL OFF."
*SEES ALTITUDE ALERT LIGHT ILLUMINATE.
*CAPT ACKNOWLEDGES.

01:07:30 LEVELS AT 7000

*SEES ALTITUDE ALERT LIGHT EXTINGUISH.
*NOTES ALTIMETER AT 7000 FEET.
*LEVELS AIRCRAFT AT 7000 FEET USING ADI, ALTIMETER AND VERTICAL SPEED INDICATOR.
*REDUCES POWER TO CRUISE SETTING.
*SETS AIRSPEED CURSOR TO 288 KNOTS.
*NOTES AIRSPEED STABLE AT 2 ENGINE CRUISE.

01:08:45 "A" HYDRAULICS SYSTEM FAILURE

*F/E REPORTS, "CAPT, A QUANTITY IS DECREASING BELOW 2.5, A PUMP LIGHTS ARE ON. WE'VE JUST LOST "A" SYSTEM".
*CAPT CALLS, "A" SYSTEM FAILURE CHECKLIST
*F/E CALLS, "CONTROL WHEEL NEUTRAL".
*CAPT REPORTS, "NEUTRAL" AND NEUTRALIZES CONTROL.
*F/E CALLS, "SPOILER SWITCH SYSTEM A, OFF"
*CAPT TURNS SPOILER SWITCH OFF.

*F/E CALLS, "STANDBY RUDDER SWITCH, ON".
*CAPT TURNS STANDBY RUDDER SWITCH ON.
*F/E CALLS, "SYSTEM A PUMP SWITCH, OFF".
*CAPT ACKNOWLEDGES.
*F/E CALLS, "AUTOPILOT ELEVATOR SERVO SYSTEM B".
*CAPT PLACES AUTO PILOT S1 SERVO TO B POSITION.
*F/E CALLS, "SYSTEM A FLUID SHUTOFF SWITCH, CLOSE".
*F/E READS, "REVIEW SYSTEM "A" LOSS ADVISORY ITEMS.
*CAPT SAYS, "CONTINUE".
*F/E READS, "CHECK WEATHER, CROSSWIND LIMIT 19 KNOTS. OBSERVE YAW DAMPER LIMITATION."
*F/E READS, "PLAN MANUAL GEAR AND ALTERNATE FLAP EXTENSION."
*F/E READS, "PLAN FLAPS 15 LANDING, USE VREF+15 KNOTS. OUTBOARD AND GROUND SPOILERS, NOSE WHEEL STEERING IS INOPERATIVE."
*F/E READS, "DO NOT OPEN GROUND INTERCONNECT AFTER LANDING."
*CAPTAIN ACKNOWLEDGES.

01:18:45 CLEARANCE TO 2600 FEET

*HEARS CENTER, "___103, DESCEND AND MAINTAIN 2600 FEET".
*HEARS F/O, "BOEING 727, OUT OF SEVEN FOR 2600.
*SEES F/O SET 2600 FEET IN ALTITUDE SELECT WINDOW
*TELLS F/O TO HAVE CENTER REQUEST THAT SMF HAVE EMERGENCY EQUIPMENT STANDING BY DUE TO ENGINE AND HYDRAULIC FAILURE, AND TO RELAY NUMBER OF PASSENGERS ABOARD AND TOTAL FUEL ON BOARD.

01:18:50 DESCENT

*CAPT CALLS, "DESCENT AND APPROACH CHECKLIST FOR "A" SYSTEM FAILURE DOWN TO FLAP EXTENSION, AND REVIEW ONE ENGINE INOPERATIVE DESCENT AND APPROACH CHECKLIST."
*F/E CALLS, "PRESSURIZATION AND COOLING DOORS, SET."
*F/E CALLS, "SEAT BELT, ON"
*F/E CALLS, "ANTI-ICE"
*CAPT RESPONDS, "NOT REQUIRED".
*F/E CALLS, "ALTIMETERS, SET AND CROSS CHECKED".
*CAPT AND F/O RESPOND, "SET AND CROSS CHECKED".
*F/E CALLS, "FLIGHT INSTRUMENTS, RADIOS, AND FDS, SET AND CROSS CHECKED".
*CAPT AND F/O RESPOND, "SET AND CROSS CHECKED".
*F/E CALLS, "FLAP INHIBIT SWITCH, INHIBIT".
*CAPT OBSERVES F/O PUT SWITCH TO INHIBIT
*F/E CALLS, "GO-AROUND EPR AND VREF + 15, SET BUGS".
*CAPT SETS HIS AIRSPEED BUG
*F/E CALLS, "FUEL, SET FOR LANDING".
*F/E CALLS, "CIRCUIT BREAKER, CHECK".
*F/E CALLS, "ALTERNATE FLAP MASTER SWITCH, ON".
*CAPT OBSERVES F/O TURN SWITCH ON".

*F/E CALLS, "FLAP LEVER, 15".
*CAPT OBSERVES F/O PLACE FLAP HANDLE TO 15
*F/E CALLS, "COMPLETE TO FLAP AND GEAR EXTENSION. THE ONLY ITEM OF INTEREST ON THE ENGINE INOP CHECKLIST IS TURNING THE RIGHT PACK SWITCH OFF. I'LL DO IT NOW. WE SHOULD USE FLAPS 15 FOR LANDING.
*CAPT, "ROGER, TURN IT OFF, ROGER, FLAPS 15 FOR LANDING".
*F/E CALLS, "STANDBY FOR MANUAL GEAR EXTENSION"
*CAPT, "STANDBY".

01:19:20 APPROACH CLEARANCE

*HEARS CENTER, " ___ 103, FROM OVER SAC FLY HEADING 310 TO INTERCEPT THE LOCALIZER FOR RUNWAY 34. CLEARED FOR THE APPROACH..
*HEARS F/O, "ROGER, VECTOR 310 DEGREES, UNDERSTAND CLEARED ILS RUNWAY 34."
*ORDERS F/O TO TUNE AND IDENTIFY THE ILS ON #1 RADIO.
*SETS COURSE WINDOW TO 344 DEGREES.

01:19:50 GEAR AND FLAP EXTENSION

*CAPT REDUCES POWER, TRIMS RUDDER AND STABILIZER.
*CAPT NOTES AIRSPEED IS 200 KNOTS.
*CAPT CALLS, "EXTEND FLAPS TO 15."
*CAPT NOTES F/O STARTING FLAP EXTENSION.
*CAPT CALLS, "GEAR HANDLE OFF."
*CAPT NOTES HANDLE IS OFF.
*CAPT CALLS, "EXTEND THE GEAR MANUALLY."
*CAPT NOTES F/E STARTING GEAR EXTENSION.
*CAPT NOTES FLAPS AT 2 DEG, AIRSPEED 190 KNOTS.
*CAPT NOTES FLAPS AT 5 DEG, AIRSPEED 160 KNOTS.
*CAPT NOTES FLAPS AT 15 DEG, AIRSPEED 150 KNOTS.

01:20:20 CROSSING SAC VOR

*STARTS LEFT TURN TO 310 DEG HEADING TO INTERCEPT LOCALIZER.

01:21:00 LANDING CHECKLIST

*CALLS, "LANDING CHECKLIST, "A" SYSTEM INOP."
*HEARS F/E, "GPWS, OFF."
*HEARS F/E, "NO SMOKING, ON."
*HEARS F/E, "IGNITION, ON."
*HEARS F/E, "GEAR, DOWN, IN, 3 GREEN."
*HEARS F/E, "ANTI-SKID, 5 RELEASES."
*HEARS F/E, "FLAPS 15, 15, GREEN LIGHT."
*HEARS F/E, "HYDRAULICS, "B" SYSTEM OK."
*HEARS F/E, "LANDING CHECKLIST COMPLETE."
*CAPTAIN ACKNOWLEDGES.

01:22:20 LOCALIZER CAPTURE

*F/O CALLS, "LOCALIZER ALIVE."
*SEES LOCALIZER IN HSI AND ADI IS CENTERED.
*SEES SPEED IS AT 150 KNOTS.
*CAPT REDUCES POWER TO SLOW TO VREF + 15
*CAPT TRIMS RUDDER AND STABILIZER
*F/O CALLS, "GLIDE SLOPE ALIVE".

01:22:45 OUTER MARKER

*HEARS OUTER MARKER AUDIO SIGNAL.
*SEES OUTER MARKER LIGHT FLASHING.
*HEARS F/O, "OUTER MARKER, ALTIMETERS AND INSTRUMENTS CROSSCHECKED."
*HEARS F/O, SACRAMENTO TOWER, ___103, OUTER MARKER INBOUND.

01:23:10 LANDING CLEARANCE

*HEARS SACRAMENTO TOWER, "___103, SACRAMENTO TOWER, WIND 340 AT 10, CLEARED TO LAND ILS 34. EMERGENCY EQUIPMENT STANDING BY.
*HEARS F/O, "103, CLEARED TO LAND."

01:23:20 CONTINUOUS APPROACH MONITOR

*MONITORS FD, ILS RAW DATA, AIRSPEED, ALTITUDE, RADAR ALTITUDE, TIME, VERTICAL VELOCITY, HSI ILS DISPLAY, HEADING, AP STATUS.

01:23:30 1000 FOOT ALTITUDE CALL

*HEARS F/O, "1000 FEET ABOVE FIELD, ALTIMETERS AND INSTRUMENTS CROSSCHECKED.
*SEES DESCENDING THROUGH 1000 FT ABOVE FIELD.
*CALLS, "CROSSCHECKED."01:24:08 500 FOOT ALTITUDE CALL

*HEARS F/O, "500 FEET ABOVE FIELD, ALTIMETERS AND INSTRUMENTS CROSSCHECKED
*SEES DESCENDING THROUGH 500 FEET ABOVE FIELD.
*CALLS, "CROSSCHECKED."

01:24:30 VISUAL CONTACT

*HEARS F/O, "100 FEET TO MINIMUMS, STROBE LIGHTS IN SIGHT."
*HEARS MIDDLE MARKER AUDIO SIGNAL.
*SEES MIDDLE MARKER LIGHT FLASHING.
*HEARS F/O, "MINIMUMS, RUNWAY IN SIGHT."
*SEES MINIMUM DESCENT ALTITUDE LIGHT IS ON.
*LOOKS AHEAD.
*SEES RUNWAY.
*SAYS, "CONTACT."

01:25:00 TOUCHDOWN AND ROLLOUT

*SEES TOUCHDOWN
*THRUST LEVERS IDLE.
*HEARS SPEEDBRAKE LEVER MOVE TO AFT POSITION.
*SENSES AUTO BRAKES ARE WORKING.
*SEES GROUND SPEED IS DECREASING.
*CONTROLS AIRPLANE ALONG RUNWAY CENTERLINE AND LOWERS NOSE GEAR TO RUNWAY SURFACE.
*RAISES REVERSE LEVERS TO INTERLOCK STOP.
*FEELS INTERLOCK RELEASE.
*MOVES REVERSE LEVERS TO AFT LIMIT STOP.
*HEARS F/O, "70 KNOTS."
*MOVES REVERSE LEVERS FORWARD AND DOWN OUT OF REVERSE THRUST.
*SEES ENGINES AT IDLE.
*PRESSES FEET ON TOP OF BRAKE PEDALS.
*CONTINUES FINAL TAXI MANUALLY.
*HEARS TOWER, "___103, HOLD ON THE RUNWAY STAY WITH ME."

APPENDIX C

FULL-MISSION SIMULATION ATC SCRIPTS

FULL-MISSION SIMULATION ATC SCRIPTS

SCRIPT 1 — SMF to SFO

FREQUENCIES:

SMF ATIS	126.75	OAK CENTER	132.65
SMF TOWER	125.7	BAY APPROACH	134.5
SAC DEPARTURE	124.5	SFO TOWER	120.5
DISPATCH FREQ.	123.55	SFO ATIS	118.85

OTHER TRAFFIC:

N56M: * VISUAL TARGET - LIGHT TWIN SOUTH OF SAC VOR
N300L: * VISUAL TARGET - LIGHT TWIN NORTH OF SJC VOR

WEATHER:

SMF ATIS: INFORMATION ALPHA. CLEAR, VISIBILITY 15, WIND 190/15, TEMPERATURE 60, DEW POINT 52, ALTIMETER 29.98. LANDING AND DEPARTING RUNWAY 16.

SFO ATIS: INFORMATION BRAVO. CLEAR, VISIBILITY 20, WIND 250/5, TEMPERATURE 59, DEW POINT 45, ALTIMETER 29.95. LANDING AND DEPARTING RUNWAYS 28.

MALFUNCTIONS:

CAPTAIN MUST HANDLE ALL COMMUNICATIONS

XX352 IS AT TAKEOFF END OF RUNWAY 16. THEY HAVE A CLEARANCE TO SFO VIA DIRECT SAC, RISTI 2 ARRIVAL, CEDES, SFO. MAINTAIN 11,000. DEPARTURE CONTROL FREQUENCY 124.5, SQUAWK 6512.

XX352: SMF TOWER, XX352 READY FOR TAKEOFF

SMF TOWER: XX352, SMF TOWER, CLEARED FOR TAKEOFF

WINDOW ONE: **OPEN - WHEN THROTTLES ADVANCE**

CLOSE - FLAPS FIVE

SMF TOWER: XX352, CONTACT DEPARTURE CONTROL (124.5)

(after XX352 calls

CLOSE WINDOW ON XX352 GIVE TIME EFFORT STRESS

SAC DEP: XX352, SAC DEPARTURE, RADAR CONTACT

WINDOW TWO:

OPEN - FLAPS UP

CLOSE - ONE MINUTE LATER

SAC DEP:	TW789, CONTACT OAK CENTER ON 132.65
TW789:	132.65, TW789
SAC DEP:	XX356, CONTACT OAK CENTER ON 132.65
SAC DEP:	DL334, CONTACT OAK CENTER ON 132.65
DL334:	OAK CENTER ON 132.65, ROGER 334
XX356:	CENTER ON 132.65, XX356
SAC DEP:	XX352, LEAVING 10,000, DO NOT EXCEED 300 KTS. FOR SPACING

CLOSE WINDOW TWO XX352 GIVE TIME EFFORT STRESS

BETWEEN WINDOWS 2 & 3, APPROX 2-3 MINUTES

(between 7,000 & 8,000 ft.)

SAC DEP:	XX352, CONTACT OAK CENTER ON 132.65
OAK CENTER:	DL334, CLEARED TO SFO VIA THE RISTI 2 ARRIVAL, MAINTAIN 11,000
DL334:	CLEARED VIA THE RISTI 2, MAINTAIN 11,000 , DL334

OAK CENTER:	DL334 TRAFFIC, 2 O'CLOCK, 6 MILES, VFR 9,500
DL334:	DL334, LOOKING
OAK CENTER:	N72T, TRAFFIC, 12 O'CLOCK, 5 MILES, CIVIL JET AT 11,000
N72T:	IN SIGHT, XXN72T
OAK CENTER:	N59B, CONTACT TRAVIS APPROACH, 127.8
N59B:	TRAVIS APPROACH ON 127.8, 58B
CESSNA 37UL	OAKLAND CENTER, THIS CESSNA 37U, WE'RE VFR AT 7,500, REQUESTING ADVISORIES TO FAT
OAK CENTER:	CESSNA 37U, ROGER, SQUAWK 3412
OAK CENTER:	CESSNA 37U, RADAR CONTACT, 3 NORTHWEST OF TRACY
OAK CENTER:	N72T, CLEAR OF TRAFFIC, CONTACT BAY APPROACH, 120.9
N72T:	BAY APPROACH, 120.9, 72T
OAK CENTER:	37U, CONTACT SCK APPROACH, 125.1
N37U:	SCK APPROACH, 125.1, GOOD DAY
OAK CENTER:	XX352, ROGER

WINDOW THREE:	**OPEN - ONE MINUTE AFTER PASSING 10,000** **CLOSE - TWO MINUTES LATER**

OAK CENTER:	XX352, CLEARED TO SFO VIA THE RISTI 2 ARRIVAL, MAINTAIN 11,000
OAK CENTER:	DL334, CONTACT BAY APPROACH ON 134.5
DL334:	134.5, DL334
OAK CENTER:	XX356, SAY YOUR SPEED
XX356:	(XXX) KNOTS
OAK CENTER:	XX352, TRAFFIC (XX) O'CLOCK, (XX) MILES, (DIRECTION) RESTRICTED BELOW YOU
OAK CENTER:	TW789, CONTACT BAY APPROACH ON 134.5

TW789: ROGER, BAY ON 134.5, TW789

OAK CENTER: N56M, TRAFFIC (XX) O'CLOCK, (XX) MILES, (DIRECTION), ABOVE YOU

N56M: IN SIGHT, 56M

OAK CENTER: XX356, CONTACT BAY APPROACH ON 134.5

XX356: 134.5, XX356

CLOSE WINDOW THREE XX352 GIVE TIME EFFORT STRESS

BETWEEN WINDOWS 3 & 4, APPROX 2 - 4 MINUTES

OAK CENTER: N56M, CONTACT TRAVIS APPROACH ON 127.8

OAK CENTER: PS751, DESCEND AND MAINTAIN 11,000, SFO ALTIMETER 29.95

PS751: DOWN TO 11,000, ALTIMETER 29.95, PS751

XX787: OAKLAND CENTER, XX787 WITH YOU DESCENDING TO FL240

OAK CENTER: XX787, OAKLAND CENTER, ROGER

OAK CENTER: PS751, REDUCE SPEED TO 250

PS751: PS751, SLOWING TO 250

OAK CENTER: NAVY441, DESCEND AND MAINTAIN 12,000 , NGZ ALT. 29.93

OAK CENTER: NAVY441, CONTACT BAY APPROACH, 310.8

UA388: OAKLAND CENTER, UA388 LEVEL 11,000

OAK CENTER: UA388, OAKLAND CENTER, ROGER, CLEARED TO SFO, VIA RISTI 2 ARRIVAL, MAINTAIN 11,000

UA388: TO SFO, VIA THE RISTI 2, MAINTAIN 11,000, UA388

N56M: ROGER, TRAVIS ON 127.8

WINDOW FOUR: **OPEN - THREE MINUTES AFTER THREE CLOSES**

CLOSE - TWO MINUTES LATER

OAK CENTER:	XX352, CONTACT BAY APPROACH ON 134.5
	(after XX352 calls)
BAY APP:	XX352, DEPART CEDES HEADING 240, INTERCEPT THE 28R LOCALIZER
BAY APP:	DL334, DESCEND AND MAINTAIN 4,000
DL334:	ROGER, DOWN TO 4,000 DL334
BAY APP:	TW789, DESCEND AND MAINTAIN 7,000
TW789:	7,000 TW789
BAY APP:	XX356, DESCEND AND MAINTAIN 7,000
XX356:	7,000 XX356
BAY APP:	TW789, DESCEND AND MAINTAIN 4,000
TW789:	4,000 ROGER TW789
BAY APP:	XX356, TRAFFIC 1 O'CLOCK, 3 MILES, SOUTHEAST BOUND ALTITUDE UNKNOWN
XX356:	XX356 LOOKING

CLOSE WINDOW FOUR XX352 GIVE TIME EFFORT STRESS

BAY APP:	XX352, TRAFFIC (XX) O'CLOCK, (XX) MILES, (DIRECTION) BELOW YOU
BAY APP:	N900L, TRAFFIC (XX) O'CLOCK, (XX) MILES, SOUTHWEST BOUND, ABOVE YOU
N900L:	IN SIGHT, 900L
BAY APP:	XX352, DESCEND AND MAINTAIN 7,000

WINDOW FIVE:

OPEN - WHEN THROTTLES AT IDLE

CLOSE - TWO MINUTES LATER

BAY APP:	DL334, (XX) MILES FROM BRIJJ, MAINTAIN 3,000 UNTIL ESTABLISHED ON THE LOCALIZER, CLEARED FOR ILS RUNWAY 28R APPROACH. CONTACT THE TOWER AT BRIJJ
BAY APP:	XX352, DESCEND AND MAINTAIN 6,000
DL334:	3,000 UNTIL ESTABLISHED, CLEARED FOR APPROACH DL334
BAY APP:	TW789, (XX) MILES FROM BRIJJ, MAINTAIN 3,000 UNTIL ESTABLISHED ON THE LOCALIZER, CLEARED FOR ILS RUNWAY 28R APPROACH.
BAY APP:	XX352, YOUR FOLLOWING COMPANY TRAFFIC 10 MILES AHEAD
TW789:	CLEARED FOR THE ILS TO 28R, TW789
BAY APP:	CONTACT THE TOWER AT BRIJJ
TW789:	ROGER, TOWER AT BRIJJ
BAY APP:	XX356, DESCEND AND MAINTAIN 4,000
XX356:	4,000 XX356
BAY APP:	XX356, SAY SPEED
XX356:	(XXX) KNOTS

CLOSE WINDOW FIVE XX352 GIVE TIME EFFORT STRESS

BETWEEN WINDOWS 5 & 6, APPROX. 2-3 MINUTES

BAY APP:	NAVY441, CONTACT NGZ TOWER, 307.2
PS751:	BAY APPROACH, PS751 WITH YOU LEVELING 11,000 AT 250 KNOTS
BAY APP:	PS751, CONTINUE DESCENT, MAINTAIN 7,000
PS751:	ROGER, ON DOWN TO 7,000, PS751
BAY APP:	PS751, FLY HEADING 240, TO INTERCEPT THE 28R LOCALIZER
PS751:	240 FOR THE INTERCEPT, PS751
BAY APP:	N4770, SAY AGAIN YOUR DESTINATION?
N4770:	WE'RE GOING TO HAYWARD, N4770

WINDOW SIX: **OPEN - LOCALIZER ALIVE**

CLOSE - PASSING LOM

BAY APP:	XX356, DESCEND AND MAINTAIN 2,000
XX356:	ROGER, 2,000 XX356
BAY APP:	XX352, DESCEND AND MAINTAIN 4,000
BAY APP:	XX356, (XX) MILES FROM BRIJJ, MAINTAIN 2,000 UNTIL ESTABLISHED ON THE LOCALIZER, CLEARED FOR ILS RUNWAY 28R APPROACH. CONTACT THE TOWER AT BRIJJ
XX356:	CLEARED FOR APPROACH, XX356
AA527:	BAY APPROACH THIS IS AA527 WITH YOU AT 11,000
BAY APP:	AA527 BAY APPROACH ROGER, DESCEND AND MAINTAIN 7,000
AA527:	OUT OF 11,000 FOR 7,000 AA527 AA527, DO YOU HAVE THE ATIS?
AA527:	ROGER, WE HAVE BRAVO
BAY APP:	AA527, TURN RIGHT HEADING 250, INTERCEPT THE 28R LOCALIZER
AA527:	250 AND INTERCEPT, AA527
BAY APP:	XX352 (XX) MILES FROM BRIJJ, CLEARED FOR THE ILS 28R APPROACH
NW248:	BAY NW248 OUT OF 7,000 FOR 11,000 REQUESTING DIRECT LIN
BAY APP:	NW248 BAY ROGER I'LL CHECK
BAY APP:	NW248 UNABLE DIRECT LIN AT THIS TIME
NW248:	NW248 ROGER
BAY APP:	AA527, DESCEND AND MAINTAIN 4,000
BAY APP:	XX352, SAY SPEED
AA527:	ROGER, DOWN TO 4,000, 527

CLOSE WINDOW SIX XX352 GIVE TIME EFFORT STRESS

BAY APP: XX352 CONTACT TOWER 120.5

(after XX352 calls)

SFO TOWER: XX352 SFO TOWER, CLEARED TO LAND 28R

SFO TOWERI: TW789 TURN LEFT NEXT TAXIWAY CONTACT GROUND ON .65

TW789I ROGER

SFO TOWERI XX356 LEFT AT THE HIGH SPEED, GROUND .65

XX356I ROGER

WINDOW SEVEN: OPEN - PASSING LMM

CLOSE - THIRTY SECONDS LATER

SFO TOWER: XX675, HOLD SHORT OF 28R

XX675: HOLDING SHORT

CLOSE WINDOW SEVEN XX352 GIVE TIME EFFORT STRESS

(after XX352 has landed)

SFO TOWER: XX352, HOLD ON THE RUNWAY, STAY WITH ME

SCRIPT 2 — SFO to SCK

FREQUENCIES:

SFO ATIS	118.85	SCK APPROACH	125.1
SFO TOWER	120.5	SCK TOWER	120.3
BAY DEPARTURE	120.9	SCK ATIS	118.25
DISPATCH FREQ.	123.55		

OTHER TRAFFIC:

N24X: * VISUAL TARGET - LIGHT TWIN NORTH OF OAK
N176B: * VISUAL TARGET - LIGHT TWIN WEST OF MOD

WEATHER:

SFO ATIS: INFORMATION BRAVO. CLEAR, VISIBILITY 20, WIND 250/5, TEMPERATURE 59, DEW POINT 45, ALTIMETER 29.95. LANDING AND DEPARTING 28.

SCK ATIS: INFORMATION FOXTROT. CLEAR, VISIBILITY 20, WIND 290/10+15, TEMPERATURE 62, DEW POINT 40, ALTIMETER29.90. LANDING AND DEPARTING 29R

MALFUNCTIONS:

NONE

XX247 IS AT TAKEOFF END OF 28L. THEY HAVE A CLEARANCE TO SCK VIA QUIET 8 TO REBAS, MOD, SIMMS, SCK. MAINTAIN 11,000. DEPARTURE FREQUENCY 120.9 SQUAWK 3642.

XX247: SFO TOWER, THIS IS XX247, READY FOR TAKEOFF

SFO TOWER: XX247 SFO TOWER, CLEARED FOR TAKEOFF

WINDOW ONE:

OPEN - THROTTLES ADVANCE

CLOSE - FLAPS FIVE

SFO TOWER: XX247, CONTACT BAY DEPARTURE (120.9)

(after XX247 calls)

CLOSE WINDOW ONE XX247 GIVE TIME EFFORT STRESS

BAY DEP: XX247, BAY DEPARTURE, RADAR CONTACT

WINDOW TWO: **OPEN - FLAPS UP**

CLOSE - ONE MINUTE LATER

PA454: BAY, THIS IS PA454 OFF OAK, OUT OF 1,000 FOR FL230

BAY DEP: PA454, THIS IS BAY DEPARTURE ROGER, RADAR CONTACT

BAY DEP: XX247, SAY YOUR SPEED

EA500: BAY, EA500 IS LEVEL AT 7,000

BAY DEP: EA500 ROGER, CLIMB AND MAINTAIN FL230

EA500: UP TO 230, EA500 THANK YOU

CP422: DEPARTURE THIS IS CP422 OUT OF (XXX) FOR 230 REQUESTING DIRECT LIN

BAY DEP: CP422, BAY DEPARTURE, RADAR CONTACT, UNABLE DIRECT LIN

CP422: ROGER

CLOSE WINDOW TWO XX247 GIVE TIME EFFORT STRESS

BAY DEP: XX241, VERIFY LEVEL AT 11,000

XX241: THAT'S AFFIRMATIVE, LEVEL 11,000, XX241

BAY DEP: XX247, TRAFFIC (XX) O'CLOCK, (X) MILES, SOUTHBOUND

BAY DEP: N24X, TRAFFIC (XX) O'CLOCK, (X) MILES, EASTBOUND

N24X:	IN SIGHT, THANK YOU, 24X

WINDOW THREE:	**OPEN - ONE MINUTE AFTER PASSING 10,000** **CLOSE - TWO MINUTES LATER**

BAY DEP:	PA454, CONTACT OAK CENTER ON 135.45
PA454:	135.45, SO LONG
BAY DEP:	XX241, CONTACT SCK APPROACH ON 125.1
XX241:	SWITCHING, XX241
BAY DEP:	XX247, DO NOT EXCEED 300 KTS. FOR SPACING
BAY DEP:	EA500, CONTACT OAK CENTER ON 128.45
EA500:	SWITCHING, 500
BAY DEP:	CP422, FLY HEADING 040, RECEIVING LIN PROCEED DIRECT
CP422:	040 FOR LIN, THANK YOU SIR
BAY DEP:	CP422, CONTACT OAK CENTER ON 132.65, GOOD DAY
CP422:	SWITCHING
BAY DEP:	XX247, CONTACT SCK APPROACH ON 125.1
SCK APP:	XX247 SCK APPROACH, ROGER

CLOSE WINDOW THREE XX247 GIVE TIME EFFORT STRESS

BETWEEN WINDOWS 3 & 4, 3 MINUTES

BARON22B:	SCK APPROACH, THIS IS BARON 22B, JUST OFF LODI, OUT OF 700 CLIMBING, REQUESTING ADVISORIES TO FAT
SCK APP:	BARON22B, ROGER, SQUAWK 4133
N22B:	SQUAWKING 4133, 22B
SCK APP:	BARON22B, RADAR CONTACT 6 NORTHEAST LODI, SCK ALT. 29.90

BARON2B:	ROGER, 29.90
SCK APP:	MAC12378, CONTACT TRAVIS APPROACH, 289.1
SCK APP:	AF70287, CONTACT CASTLE APPROACH, 257.9
SCK APP:	BUFFY11, CLIMB AND MAINTAIN FL230
SCK APP:	BUFFY11, CONTACT OAKLAND CENTER, 284.6

WINDOW FOUR: **OPEN - THREE MINUTES AFTER WINDOW THREE CLOSES**

CLOSE - TWO MINUTES LATER

SCK APP:	XX241, DESCEND AND MAINTAIN 6,000
XX241:	ROGER OUT OF 11,000 FOR 6,000, XX241
SCK APP:	XX247, YOUR FOLLOWING COMPANY TRAFFIC 15 MILES AHEAD
SCK APP:	XX241, TURN LEFT HEADING 070
XX241:	LEFT TO 070, XX241
SCK APP:	XX241, TRAFFIC 12 O'CLOCK, 4 MILES SOUTHBOUND ALTITUDE UNKNOWN
XX241:	LOOKING
SCK APP:	PS1278, CONTACT OAK CENTER ON 135.45
PS1278:	135.45, PS1278
CO225:	SCK APPROACH CO225 WITH YOU AT 11,000
SCK APP:	CO225 SCK APPROACH ROGER

CLOSE WINDOW FOUR XX247 GIVE TIME EFFORT STRESS

BETWEEN WINDOW 4 & 5, APPROX. 2-3 MINUTES

SCK APP:	BARON22B, CONTACT CASTLE APPROACH, 125.2
BARON22B:	ROGER, CASTLE APPROACH, 125.2, BARON22B

SCK APP:	CITATION 37L, CLIMB AND MAINTAIN FL230
CITATION37L:	CLIMB AND MAINTAIN FL230, CITATION 37L
SCK APP:	CITATION 37L, CONTACT OAKLAND CENTER, 124.2
CITATION37U:	OAKLAND CENTER ON 124.2, CITATION 37U
SCK APP:	CHEROKEE 2370J, CLIMB AND MAINTAIN 5,000
N2370J:	OUT OF 2,700 FOR 5,000 , CHEROKEE 70J
SCK APPI	CHEROKEE 70J, CONTACT BAY APPROACH, 135.4
N2370J:	CONTACT BAY ON 135.4 , CHEROKEE 70J
SCK APP:	CESSNA 23561, CONTACT SCK TOWER, 120.3
N233561:	TOWER ON 120.3 , CESSNA 561
SCK APP:	XX247 DESCEND TO CROSS 8 WEST OF MOD AT AND MAINTAIN 6,000

WINDOW FIVE:

OPEN - THROTTLES AT IDLE

CLOSE - TWO MINUTES LATER

SCK APP:	XX247, TRAFFIC (XX) O'CLOCK, (XX) MILES, SOUTHBOUND, BELOW YOU
SCK APP:	N176B, TRAFFIC (XX) O'CLOCK, (XX) MILES, EASTBOUND, A B727 ABOVE YOU
N176B:	IN SIGHT, 176B
SCK APP:	N176B, CONTACT BAY APPROACH ON 134.5
N176B:	BAY ON 134.5, 76B, GOOD DAY
SCK APP:	XX241, DESCEND AND MAINTAIN 3,000
XX241:	3,000, XX241
SCK APP:	XX241, TRAFFIC (XX) O'CLOCK, (XX) MILES, SOUTHBOUND, VFR AT 2,500
XX241:	LOOKING, XX241
SCK APP:	CO225 DO YOU HAVE THE SCK ATIS?

CO225: THAT'S AFFIRM WE HAVE FOXTROT

SCK APP: XX247, DEPART MOD HEADING 320 AND INTERCEPT THE 29R LOCALIZER

CLOSE WINDOW FIVE — XX247 GIVE TIME EFFORT STRESS

BETWEEN WINDOWS 5 & 6, APPROX. 4-5 MINUTES

SCK APP: CHEROKEE 32506, CLIMB AND MAINTAIN 8,000, SAC ALTIMETER 29.91

N32506: CHEROKEE 506, OUT OF 6,000 FOR 8,000, ALTIMETER 29.91

SCK APP: MOONEY 231DR, CLIMB AND MAINTAIN 15,000 , SCK ALTIMETER 29.90

N231DR: OUT OF 9,000 FOR 15,000 , ALTIMETER 29.90, MOONEY 31DR

SCK APP: CHEROKEE 506, CONTACT OAKLAND CENTER, 124.2

N32506: OAKLAND CENTER ON 124.2, CHEROKEE 506, SO LONG

PS1220: SCK APPROACH, THIS PS1220 WITH YOU CLIMBING TO 7,000

SCK APP: PS1220, SCK APPROACH, RADAR CONTACT, CLIMB AND MAINTAIN 11,000, AND VERIFY PRESENT ALTITUDE

PS1220: WE'RE OUT OF 1,800 , NOW CLIMBING TO 11,000, PS1220

SCK APP: ROGER, SAC ALTIMETER IS 29.91

PS1220: 29.91

SCK APP: PS1220, CONTACT SAC APPROACH, 125.6

PS1220: 125.6, PS1220, BYE

WINDOW SIX:

OPEN - LOCALIZER ALIVE (PASSING MOD)

CLOSE - PASSING LOM

SCK APP: N905T, TRAFFIC (XX) O'CLOCK, (XX) MILES, EASTBOUND, A CIVIL JET ABOVE YOU

N905T:	IN SIGHT, 905T
SCK APP:	XX241, 6 MILES FROM JOTLY, CLEARED FOR ILS 29R APPROACH
XX241:	CLEARED FOR THE APPROACH, XX241
	(after XX247 passes MOD)
SCK APP:	XX247, DESCEND AND MAINTAIN 3,000
SCK APP:	CO225, DESCEND AND MAINTAIN 6,000
CO225:	6,000, CO225
SCK APP:	XX241, CONTACT SCK TOWER ON 120.3
XX241:	SWITCHING, XX241
SCK APP:	CO225, FLY HEADING 070, VECTORS TO FINAL
CO225:	LEFT TO 070 FOR CO225
SCK APP:	CO225, DESCEND AND MAINTAIN 4,000
CO225:	ROGER, DOWN TO 4,000, CO225
XX241:	APPROACH THIS IS XX241, WHAT WAS THAT FREQUENCY AGAIN
SCK APP:	XX241, SCK TOWER ON 120.3
XX241:	OKAY, 120.3, THANK YOU
SCK APP:	N905T, VERIFY YOUR DESTINATION AND DO YOU WANT AN IFR CLEARANCE?
N905T:	AFFIRMATIVE AND WERE GOING TO SJC, 905T
SCK APP:	CO225, DESCEND AND MAINTAIN 3,000
CO225:	3,000, CO225
SCK APP:	N905T, CONTACT BAY APPROACH ON 121.3, THEY HAVE YOUR REQUEST FOR IFR
N905T:	121.3, 905T
SCK APP:	XX247, (XX) MILES FROM JOTLY, CLEARED FOR THE ILS 29R APPROACH

CLOSE WINDOW SIX | XX247 GIVE TIME EFFORT STRESS

SCK APP:	XX247 CONTACT TOWER ON 120.3
	(after XX247 calls)
SCK TOWER:	XX247 SCK TOWER, CLEARED TO LAND 29R, WIND 290 AT 12
SCK TOWER:	XX241, TURN LEFT INTERSECTION, GROUND ON POINT 9
XX241:	ROGER
SCK TOWER:	N52E, SAY YOUR POSITION NOW
N52E:	WERE 8 MILES EAST OF THE AIRPORT AT 2,000 FOR LANDING, 52E
SCK TOWER:	52E ROGER, ENTER LEFT TRAFFIC RUNWAY 29, REPORT DOWNWIND
N52E:	52E, ROGER

WINDOW SEVEN:

OPEN - PASSING LMM

CLOSE - THIRTY SECONDS LATER

CO225:	SCK TOWER, CO225 WITH YOU JUST OUTSIDE THE MARKER
SCK TOWER:	CO225 ROGER, NUMBER TWO

CLOSE WINDOW SEVEN | XX247 GIVE TIME EFFORT STRESS

(after XX247 is on runway)

SCK TOWER: XX247, HOLD ON THE RUNWAY, STAY WITH ME

SCRIPT 3 — LAX to SFO to OAK to SMF

FREQUENCIES:

LAX ATIS	133.8	OAK CENTER	133.7
LAX TOWER	133.9		125.45
LAX DEPARTURE	125.2		132.65
LAX CENTER	135.5	BAY APPROACH	135.4
	125.65	OAK TOWER	127.2
	133.7	BAY DEPARTURE	120.9
	125.45	SAC APPROACH	125.6
DISPATCH FREQ.	135.95	SMF TOWER	125.7
OAK ATIS	128.5	SMF ATIS	126.75
SFO ATIS	118.85		

OTHER TRAFFIC:

DL501: * VISUAL TARGET WHEN CAB PASSES 13,000, 1,000 FT. BELOW
PS1282: * VISUAL TARGET WHEN CAB IS AT FL310, 2,000 FT. ABOVE
XX370: * VISUAL TARGET WHEN CAB IS NORTHWEST OF MQO VOR, 2,000 FT ABOVE N2578J: * VISUAL TARGET WHEN CAB IS LEVEL AT 7,000, OFF OAK

WEATHER:

LAX ATIS: INFORMATION DELTA. CLEAR, VISIBILITY 15. WIND CALM, TEMPERATURE 60, DEW POINT 40, ALTIMETER 29.90. LANDING 24L, DEPARTING 24R.

SFO ATIS: INFORMATION ECHO. MEASURED CEILING 500 OVERCAST, VISIBILITY 1 FOG, WIND 280/5, TEMPERATURE 59, DEW POINT 55, ALTIMETER 29.87. LANDING AND DEPARTING RUNWAYS 28.

OAK ATIS: INFORMATION GOLF. 200 SCATTERED MEASURED 400 OVERCAST, VISIBILITY 1 FOG, WIND CALM, TEMPERATURE 55 DEW POINT 54, ALTIMETER 29.86. LANDING AND DEPARTING 29.

SMF ATIS: INFORMATION HOTEL. CLEAR, VISIBILITY 15, WIND 340/10 TEMPERATURE 60, DEW POINT 52, ALTIMETER 30.00. LANDING AND DEPARTING 34.

MALFUNCTIONS:

NO AUTOPILOT
15 MINUTES INTO FLIGHT - "A" SYSTEM WARNING LIGHT ACTIVATED
PASSING OAK LMM and 1,500 ft. - #1 ENGINE SHUT DOWN
AFTER MISSED APPROACH AT OAK and LEAVING 6,800 ft. - "A" SYSTEM FAILURE

XX103 IS AT TAKEOFF END OF 24R. THEY HAVE A CLEARANCE TO SFO VIA THE VENTURA 9 DEPARTURE DIRECT RZS J501 BIG SUR, BIG SUR PROFILE DESCENT TO SFO. MAINTAIN 30, EXPECT FL310 5 MINUTES AFTER DEPARTURE. DEPARTURE FREQUENCY IS 125.2, SQUAWK 3254.

XX103: LAX TOWER, THIS IS XX103 READY FOR TAKEOFF

LAX TOWER: XX103 LAX TOWER, CLEARED FOR TAKEOFF

WINDOW ONE:

OPEN - THROTTLES ADVANCE

CLOSE - FLAPS FIVE

(after passing 500 feet)

LAX TOWER: XX103, CONTACT LAX DEPARTURE (125.2)

(after XX103 calls)

LAX DEP: XX103 LAX DEP, RADAR CONTACT

CLOSE WINDOW ONE XX103 GIVE TIME EFFORT STRESS

WINDOW TWO:

OPEN - FLAPS UP

CLOSE - ONE MINUTE LATER

LAX DEP: XX103, TURN RIGHT HEADING 280, RECEIVING VTU PROCEED DIRECT. CLIMB AND MAINTAIN FL230

LAX DEP: XX108, FLY HEADING 280, JOIN J501, RESUME YOUR OWN NAVIGATION CLIMB AND MAINTAIN FL230, CONTACT LAX CENTER ON 135.5

XX108: JOIN J501, FL230, CHANGING, XX108

TW344: DEPARTURE, THIS IS TW344 OUT OF 700 FOR 3,000

LAX DEP:	TW344 LAX DEPARTURE, RADAR CONTACT. CLIMB AND MAINTAIN 15,000
TW344:	15,000, TW344
UA122:	LAX DEPARTURE UA122 WITH YOU OUT OF 800 FOR 3,000
LAX DEP:	UA122 LAX DEPARTURE, RADAR CONTACT, TURN RIGHT HEADING 010 VECTORS PMD, CLIMB AND MAINTAIN 15,000
UA122:	RIGHT TO 010 AND UP TO 15,000, UA122

CLOSE WINDOW 2 XX103 GIVE TIME EFFORT STRESS

BETWEEN WINDOWS 2 & 3, APPROX 10-15 MINUTES

LAX DEP:	XX103 CONTACT LAX CENTER ON 135.5
	(after XX103 calls)
LAX CENTER:	XX103 LAX CENTER ROGER
LAX CENTER:	XX108, CLIMB AND MAINTAIN FL310, CONTACT LAX CENTER ON 125.65
XX108:	UP TO 310 AND 125.65, SO LONG
LAX CENTER:	DL501, TRAFFIC (XX) O'CLOCK, (XX) MILES, NORTHWEST BOUND ABOVE YOU
DL501:	LOOKING, THANK YOU DL501
LAX CENTER:	XX103, TRAFFIC (XX) O'CLOCK, (XX) MILES, SOUTHEAST BOUND BELOW YOU
LAX CENTER:	XX103, CLIMB AND MAINTAIN FL310, CONTACT LAX CENTER ON 125.65
	(after XX103 calls)
LAX CENTER:	XX103 LAX CENTER, FLXXX ROGER
LAX CENTER:	MX1755, CLEARED DIRECT PMD, REST OF ROUTE UNCHANGED
MX1755:	DIRECT PMD, MX1755
LAX CENTER:	AL260, DESCEND AND MAINTAIN 15,000, THE BUR ALTIMETER 29.89, CONTACT LAX CENTER ON 135.5

AL260:	15,000 AND LAX ON 135.5, AL260
LAX CENTER:	XX108, SAY YOUR MACH NUMBER
XX108:	.80
LAX CENTER:	ROGER
LAX CENTER:	ASPEN 72, VERIFY ALTITUDE
LAX CENTER:	ASPEN 72, ROGER, CONTACT OAKLAND CENTER 338.2
LAX CENTER:	CLIPPER 220, CONTACT LAX CENTER 135.5
CLIPPER 220:	LAX CENTER, AH.. 135.5, CLIPPER 220, GOOD DAY
LAX CENTER:	PS1914, CLEARED DIRECT BSR, MAINTAIN FL350
PS1914:	DIRECT BSR NOW, AT 350, PS1914
LAX CENTER:	DACO 11, TURN LEFT HEADING 090, DIRECT PMD WHEN RECEIVING
AA252:	LAX CENTER, AA252 AT FL330
LAX CENTER:	AA252, ROGER, 330
LAX CENTER:	CO152, RADAR SERVICE TERMINATED, 10 NORTHEAST OF BITTY, CLEARED TO ENROUTE FREQUENCIES.
CO152:	CLEARED TO ENROUTE, CO152, SO LONG

WINDOW THREE:

OPEN - ONE MINUTE AFTER FL300

CLOSE - TWO MINUTES

LAX CENTER:	XX103, TRAFFIC (XX) O'CLOCK, (XX) MILES, EASTBOUND AT FL330
LAX CENTER:	PS1282, TRAFFIC (XX) O'CLOCK, (XX) MILES, NORTHWEST BOUND AT FL310
PS1282:	LOOKING, 1282
LAX CENTER:	AA600, DESCEND AND MAINTAIN FL250, CLEARED DIRECT FLW, DIRECT LHS
AA600:	DOWN TO 250, DIRECT FLW DIRECT LHS, THANK YOU, AA600

LAX CENTER:	PS1282 CLEAR OF TRAFFIC
PS1282:	THANK YOU
LAX CENTER:	XX108, CONTACT OAK CENTER ON 133.7
XX108:	133.7, GOOD NIGHT
LAX CENTER:	PS1282, CONTACT LAX CENTER ON 127.35
PS1282:	127.35, SWITCHING
LAX CENTER:	XX103, SAY YOUR MACH NUMBER

CLOSE WINDOW THREE XX103 GIVE TIME EFFORT STRESS

(company will call XX103 via SELCAL and tell them to divert to OAK due to a power failure at SFO) (1 to 1 1/2 min. after 3 closes)

BETWEEN WINDOWS 3 & 4, 3 MINUTES

LAX CENTER:	PS1914, CONTACT OAKLAND CENTER, 133.7
PS1914:	OAKLAND ON 133.7, PS1914, GOOD NIGHT
LAX CENTER:	DACO 11, CONTACT LAX CENTER, 129.1
DACO11:	LAX CENTER ON 129.1, DACO 11
UA372:	LAX CENTER, UA372 REQUESTING FL370
LAX CENTER:	UA372, ROGER, CLIMB AND MAINTAIN FL370, REPORT REACHING
UA372:	OUT OF 350 FOR 370, WE'LL REPORT REACHING, UA372
LAX CENTER:	US AIR 118, FLY HEADING 200, UNTIL RECEIVING FIM THEN PROCEED DIRECT
US AIR 118:	LEFT TO 200, DIRECT WHEN RECEIVING, US AIR 118

WINDOW FOUR: **OPEN - THREE MINUTES AFTER THREE CLOSES**

CLOSE - TWO MINUTES LATER

LAX CENTER: XX103 CONTACT OAK CENTER ON 133.7

(after XX103 calls)

OAK CENTER: XX103 OAK CENTER, FLXXX

JL557: CENTER, THIS JL557 WITH YOU AT FL290 REQUESTING FL310 IF IT'S AVAILABLE

OAK CENTER: JL557 OAK CENTER, CLIMB AND MAINTAIN FL310

JL557: UP TO 310, THANK YOU, JL557

OAK CENTER: UA921, TRAFFIC (XX) O'CLOCK, (XX) MILES, NORTHBOUND, CLIMBING OUT OF 290 FOR 310

UA921: LOOKING 921

OAK CENTER: XX108, YOUR NOW CLEARED TO THE OAK AIRPORT VIA THE SFO RUNWAY 28 BIG SUR PROFILE DESCENT. DEPART MENLO HEADING 340 AND INTERCEPT THE ILS RUNWAY 29 FINAL APPROACH COURSE. START YOUR DESCENT NOW AND CONTACT THE OAK CENTER ON 125.45.

XX108: THE BIG SUR PROFILE TO OAK, XX108 CHANGING

OAK CENTER: NW20, CLEARED DIRECT OAL, MAINTAIN FL330, REST OF ROUTE REMAINS THE SAME

NW20: *DIRECT OAL, NW20, WE APPRECIATE THAT*

OAK CENTER: XX108, CONTACT OAK CENTER ON 125.45

XX108: 125.45, SO LONG

(after XX103 calls requesting clearance to OAK)

OAK CENTER: XX103 ROGER, CLEARED TO THE OAK AIRPORT VIA THE SFO RUNWAY 28 BSR PROFILE DESCENT. DEPART MENLO HEADING 340 AND INTERCEPT THE ILS RUNWAY 29 FINAL APPROACH COURSE. MAINTAIN FL 310 FOR NOW

CLOSE WINDOW FOUR XX103 GIVE TIME EFFORT STRESS

OAK CENTER: XX103, TRAFFIC (XX) O'CLOCK, (XX) MILES, SOUTHEAST BOUND, FL330

OAK CENTER: XX103, START YOUR DESCENT NOW

WINDOW FIVE:	**OPEN - THROTTLES AT IDLE** **CLOSE - TWO MINUTES LATER**

OAK CENTER:	XX103, CONTACT CENTER ON 125.45
	(after XX103 calls)
OAK CENTER:	XX103, ROGER
PA841:	CENTER, PA841 WITH YOU AT 200
OAK CENTER:	PA841 OAK CENTER ROGER
OAK CENTER:	AL307, CLIMB AND MAINTAIN FL230, EXPECT HIGHER IN 30 MILES
AL307:	FL230, AL307
OAK CENTER:	XX108, REDUCE SPEED TO 250 KNOTS FOR SEQUENCING
XX108:	250 ON THE SPEED, 108
OAK CENTER:	XX108, CONTACT BAY APPROACH ON 134.5
XX108:	BAY ON 134.5, XX108
OAK CENTER:	AL307, CONTACT OAK CENTER ON 134.55
AL307:	CENTER ON 134.55, AL307
OAK CENTER:	XX103, REDUCE TO 250 KNOTS

CLOSE WINDOW FIVE — XX103 GIVE TIME EFFORT STRESS

	(after XX103 leaves FL190)
OAK CENTER:	XX103, CONTACT BAY APPROACH ON 134.5
	(after XX103 calls)
BAY APP:	XX103 BAY APPROACH ROGER, FLY HEADING 330, VECTORS TO OAK, DESCEND AND MAINTAIN 6,000, DO YOU HAVE THE OAK ATIS?

BAY APP:	XX108, DESCEND AND MAINTAIN 4,000
XX108:	ROGER, DOWN TO 4,000, XX108
BAY APP:	XX108, TURN LEFT HEADING 310 AND INTERCEPT THE LOCALIZER
XX108:	310 FOR THE INTERCEPT XX108
BAY APP:	XX108, DESCEND AND MAINTAIN 3,000
XX108:	3,000, XX108
BAY APP:	PS1492, REDUCE SPEED TO 180 KTS
PS1492:	BACK TO 180, PS1492
BAY APP:	VVPM34 CONTACT BAY APPROACH ON 346.0
BAY APP:	XX103, DESCEND AND MAINTAIN 4,000
BAY APP:	XX108, (XX) MILES FROM MARCE, MAINTAIN 2,500 UNTIL ESTABLISHED ON THE LOCALIZER, CLEARED FOR THE ILS 29 APPROACH
XX108:	2,500 UNTIL ESTABLISHED, CLEARED FOR APPROACH, XX108
BAY APP:	VVPM32 CONTACT BAY APPROACH ON 325.2
BAY APP:	XX103, DESCEND AND MAINTAIN 3,000
BAY APP:	XX103, FLY HEADING (XXX) AND INTERCEPT THE LOCALIZER

WINDOW SIX: **OPEN - LOCALIZER ALIVE (10 NW OF SJC)**

CLOSE - PASSING LOM

BAY APP:	XX103, (XX) MILES FROM MARCE, MAINTAIN 2,500 UNTIL ESTABLISHED ON THE LOCALIZER, CLEARED FOR THE ILS 29 APPROACH
BAY APP:	XX108, CONTACT TOWER ON 127.2
XX108:	CHANGING
N693X:	BAY THIS IS N693X, WE'VE DECIDED TO GO TO SJC
BAY APP:	N693X ROGER, FLY HEADING 100, VECTORS TO SJC

N693X:	HEADING 100, ROGER
BAY APP:	N693X CLIMB AND MAINTAIN 5,000
N693X:	UP TO 5,000, 693
BAY APP:	N693X, CONTACT BAY ON 120.1
N693X:	120.1, N693X
BAY APP:	N57U, TRAFFIC 11 O'CLOCK 4 MILES SOUTHEAST BOUND
N57U:	WE HAVE HIM, THANK YOU
BAY APP:	N57U, SQUAWK 1200, RADAR SERVICE TERMINATED, FREQUENCY CHANGE APPROVED
N57U:	57U THANK YOU, GOOD DAY

(within three minutes after window six opens)

BAY APP:	XX103, CONTACT TOWER ON 127.2

(after XX103 calls)

OAK TOWER:	XX103 OAK TOWER, CLEARED TO LAND RUNWAY 29, THE RVR IS NOW 2,000 BUT IT IS UP AND DOWN, WIND CALM
OAK TOWER:	PA450, CONTACT GROUND .65
PA450:	ROGER

(after XX103 is inside the outer marker)

CLOSE WINDOW SIX XX103 GIVE TIME EFFORT STRESS

OAK TOWER:	XX103, THE RVR IS LESS THAT 1,000 REQUEST INTENTIONS

WINDOW SEVEN:

OPEN - PASSING LMM

CLOSE - THIRTY SECONDS LATER

OAK TOWER:	XX108, CONTACT BAY DEPARTURE ON 120.9
XX108:	CHANGING, XX108

CLOSE WINDOW SEVEN XX103 GIVE TIME EFFORT STRESS

(after XX103 passes 2,000 feet on missed approach)

WINDOW EIGHT: **OPEN - PASSING 2,000**

CLOSE - TWO MINUTES

OAK TOWER:	XX103, CONTACT BAY DEPARTURE ON 120.9
	(after XX103 calls)
BAY DEP:	XX103 BAY DEPARTURE, RADAR CONTACT, LEAVING 3,000, TURN RIGHT HEADING 030, RECEIVING SAC PROCEED DIRECT, CLIMB AND MAINTAIN 7,000
BAY DEP:	XX108, CONTACT OAK CENTER ON 132.65
XX108:	132.65, XX108
BAY DEP:	NW473, FLY HEADING 120 FOR AVE, DIRECT WHEN ABLE
NW473:	DIRECT AVE, THANKS
BAY DEP:	NW473, CONTACT OAK CENTER ON 123.65
NW473:	123.65 CHANGING

CLOSE WINDOW EIGHT XX103 GIVE TIME EFFORT STRESS

WINDOW NINE: **OPEN - ONE MINUTE AFTER 6,800 FT.**

CLOSE - TWO MINUTES LATER

BAY DEP:	XX103, CONTACT OAK CENTER ON 132.65
	(after XX103 calls)

OAK CENTER: XX103, OAK CENTER ROGER

OAK CENTER: XX108, CONTACT SAC APPROACH ON 125.6

XX108: ROGER, 125.6, SO LONG

OAK CENTER: PS1254, CLIMB AND MAINTAIN FL 230

PS1254: 230, 1254

OAK CENTER: PI670, CONTACT THE CENTER ON 135.45

PI670: 135.45,670

CLOSE WINDOW NINE XX103 GIVE TIME EFFORT STRESS

(three to four minutes before 10 opens)

OAK CENTER: XX103, CONTACT SAC APPROACH ON 125.6

(after XX103 calls)

SAC APP: XX103 SAC APPROACH ROGER, DESCEND AND MAINTAIN 5,000

SAC APP: N498J, TURN LEFT HEADING 120 FOR TRAFFIC

N498J: 120 ROGER, N498J

SAC APP: XX108, (XX) MILES FROM LANEE, MAINTAIN 3,000 UNTIL ESTABLISHED ON THE LOCALIZER, CLEARED FOR THE ILS 34 APPROACH

XX108: 3,000 UNTIL ESTABLISHED, CLEARED FOR APPROACH, XX108

WINDOW TEN: **OPEN - LOCALIZER ALIVE (15 SE OF SAC)**

CLOSES - PASSING LOM

SAC APP: XX103, TURN LEFT HEADING XXX AND INTERCEPT THE 34 LOCALIZER DESCEND AND MAINTAIN 3,000

SAC APP: N498J, TRAFFIC NO LONGER A FACTOR, TURN RIGHT HEADING 140, PROCEED DIRECT MOD, RESUME YOUR OWN NAVIGATION

N498J: DIRECT MOD, THANK YOU, N498J

SAC APP:	XX103, (XX) MILES FROM LANEE, MAINTAIN 3,000 UNTIL ESTABLISHED ON THE LOCALIZER, CLEARED FOR THE ILS 34 APPROACH
SAC APP:	XX108, CONTACT SMF TOWER ON 125.7
XX108:	CHANGING
SAC APP:	N498J, CLIMB AND MAINTAIN FL 230
N498J:	FL 230 ROGER
SAC APP:	N498J, CONTACT OAK CENTER ON 132.65
N498J:	132.65, N498J
SAC APP:	XX103, SAY SPEED

CLOSE WINDOW TEN — XX103 GIVE TIME EFFORT STRESS

SAC APP: XX103, CONTACT SMF TOWER ON 125.7

(after XX103 calls)

SMF TOWER: XX103 SMF TOWER WIND 340 AT 10, CLEARED TO LAND, EMERGENCY EQUIPMENT IS STANDING BY

WINDOW ELEVEN:

OPEN - PASSING LMM

CLOSE - THIRTY SECONDS LATER

SMF TOWER:	UA553, CONTACT DEPARTURE
UA553:	CHANGING

(after XX103 lands)

CLOSE WINDOW ELEVEN — XX103 GIVE TIME EFFORT STRESS

SMF TOWER: XX103, HOLD ON THE RUNWAY, STAY WITH ME

☆U.S. GOVERNMENT PRINTING OFFICE: 1989 - 748-056/24044